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Cost and Performance Report

(SI-0310)

Portable System for Field-Feeding Greywater Remediation and Recycling

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ACRONYMS AND ABBREVIATIONS

AFSC	Advanced Food Sanitation Center
AVG	average
BOD	biological oxygen demand
CASCOM	Combined Arms Support Command
CBOD	carbonaceous biological oxygen demand
CK	containerized kitchen
COD	Chemical Oxygen Demand
CFD	Combat Feeding Directorate
COTS	commercial off-the-shelf
CPVC	chlorinated polyvinyl chloride
CU	color units
CWA	Clean Water Act
ECAM	Environmental Cost Analysis Methodology
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FSC	food sanitation center
gpd	gallons per day
gph	gallons per hour
hp	horsepower
KP	kitchen police
LCCE	life-cycle cost estimate
MANPRINT	MANpower and PeRsonnel INTegration
MBU	Modern burner unit
METT-T	Mission, Enemy, Terrain, Troops & Time Available
MRE	Meals, Ready-To-Eat
MTR	Membrane Technology Research
MWCO	molecular weight cut-off
NSC	Natick Soldier Center
NTU	nephelometric turbidity unit
O&G	oil and grease
OFIG	Operational Forces Integration Group
ORD	Operational Requirements Document

P/2	Pollution Prevention (finance software)
P3I	pre-planned product improvement
PM	program manager
SOP	standard operating procedure
SU	standard units
TDS	Total Dissolved Solids
TPhos	total phosphorous
TSS	total suspended solids
USACHPPM	U.S. Army Center for Health Promotion and Preventative Medicine
VAC	volts, alternating current
VCD	vapor compression distillation or vapor compression distiller

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1.0 EXECUTIVE SUMMARY

The U. S. Army requires a portable greywater treatment system to remediate and recycle dirty sink water from its field feeding and sanitation operations. A greywater recycling system is expected to reduce field kitchen demand for fresh water by 55% and wastewater hauling expenses by 80%.

Under an Environmental Security Technology Certification Program (ESTCP) funded project, three systems were demonstrated at Fort Lee, Virginia, in August 2004 as part of the Log Warrior Training Exercise. The field test lasted 2 weeks and each of the three systems was operated outdoors treating water created by actual field feeding operations. Water samples were taken before and after treatment. Systems were evaluated for water quality, percent reduction of contaminants, permeate flow rate, weight, and size.

There are no firm Environmental Protection Agency (EPA) regulations regarding the quality of recycled greywater for use in ware washing, so for the purposes of this study, the water was considered to be recyclable if it met the EPA secondary treated water quality outlined in the Code of Federal Regulations, 40 CFR 133.102[1]. This is defined by the following: biological oxygen demand (BOD) of 30 mg/L or less, total suspended solids (TSS) of 30 mg/L or less, pH between 6 and 9. In addition, recyclable water should have a turbidity of 5 nephelometric turbidity units (NTU) or less. The rationale for specifying secondary treated water is twofold: the treated greywater would be considered clean enough if it should be accidentally discharged to surface water such as a lake or stream, and most states with greywater reuse regulations[2] base their water quality standards on the secondary treatment standard. In addition, each system's process rate was required to be fast enough to process the entire bulk of greywater before the next meal. The following tables summarize the results and indicate whether the treatment systems passed or failed to meet any of the requirements.

Table ES-1. System Performance Summary.

System	Technology	Weight (lbs)	Permeate Flow Rate (gph)
Infinitex Splitter XD	Spiral-Wound ultrafiltration	150 PASS	18 PASS
Bristol International	Tubular ultrafiltration	150 PASS	16 PASS
Ovation Products	Vapor compression distillation	300 FAIL	23 PASS

Table ES-2. System Performance Summary.

System	Permeate Quality					Volume Reduction
	BOD (mg/L)	TSS (mg/L)	O&G (mg/L)	Turbidity (NTU)	pH	
Infinitex Splitter XD	291.2 FAIL	3.8 PASS	6.9	4.7 PASS	6.1 PASS	91%
Bristol International	447.3 FAIL	28.4 PASS	62.2	12.9 FAIL	5.8 FAIL	77%
Ovation Products	17.3 PASS	1.4 PASS	5.6	2.1 PASS	7.0 PASS	88%

The Ovation Products' vapor compression distillation (VCD) system produced the best quality permeate at an average flow rate of 23 gallons per hour (gph). As shown in Table ES-1 and Table ES-2, the permeate had an average BOD of 17.3 mg/L, TSS of 1.3 mg/L, oil and grease (O&G) of 5.6 mg/L, and turbidity of 2.1 NTU. It reduced the volume of greywater by 88%, the BOD by 99%, the TSS by 99%, the O&G by 96%, and the turbidity by 99%. It was, however, the heaviest system (weighing over 300 lbs) and was not considered field-worthy in its current configuration.

The permeate from Infinitex's Splitter XD ultrafilter had a BOD higher than the requirement but performed well in every other category. It reduced the volume of greywater by 91% and operated at an average flow rate of 18 gph. It reduced the BOD by 78%, TSS by 98%, O&G by 90%, and turbidity by 91%. The permeate had an average BOD of 291.2 mg/L, TSS of 3.8 mg/L, O&G of 6.9 mg/L, and turbidity of 4.7 NTU.

The results also showed that Bristol International's tubular ultrafilter did not produce an acceptable permeate; it had a BOD of 447.3 mg/L, TSS of 28.4 mg/L, pH of 5.8, and turbidity of 12.9 NTU. As a result of its poor performance, the cost analysis for this system was not performed.

The VCD system displayed exceptional water quality but had a physical configuration that was too heavy and complicated while the ultrafilter's physical configuration was rugged and lightweight but displayed a sub-par water quality. A one-year follow-on study is recommended to test Ovation Product's next generation prototype and work with the Army's Surgeon General to develop new guidelines for greywater recycling.

The cost savings realized by either of these systems will be significant, as they will drastically reduce the cost of potable water and greywater disposal. Based on average water and disposal costs, the estimated saving for the ultrafiltration system is $32.5 million per year for 25 years. The VCD system will save slightly more because of lower capital costs. It is estimated to save $33 million per year for 25 years.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

Military field-feeding generates hundreds of gallons of greywater each day, mostly the by-product of washing cookware after the meal. Current dishwashing operations use a three-sink food sanitation center (FSC) that requires approximately 250 gallons of fresh water per day, and generates an equivalent amount of greywater. The current disposal approach is to store the greywater in large sump tanks or bladders and then backhaul it for proper disposal. This becomes a logistical and environmental burden because local storage fills quickly, and contracted waste removal services are expensive and can be hard to coordinate with erratic greywater generation. This can result in disposal of untreated greywater to the ground, which poses health problems and harms the environment.

A water treatment and/or recycling system is needed to reduce water consumption and greywater disposal while reducing the potential environmental impact. A requirement for such a device is stated as a pre-planned product improvement (P3I) in the Operational Requirements Document (ORD) 3 for the FSC currently being procured by the Army. Three greywater reduction systems are being considered—two different configurations of ultrafiltration (spiral-wound and tubular) and vapor compression distillation. In this study, the spiral-wound ultrafiltration technology is represented by the Splitter XD by Infinitex (Clarence Center, New York), the tubular ultrafiltration by Bristol International (Bristol, Rhode Island), and VCD by Ovation Products Inc. (Nashua, New Hampshire).

2.2 PROCESS DESCRIPTION

2.2.1 Infinitex's Splitter XD Ultrafilter

The Splitter XD is a small, commercial off-the-shelf (COTS) ultrafiltration system that utilizes a semipermeable spiral-wound membrane in a cross flow configuration to filter water. Ultrafiltration membranes typically have molecular weight cut-off (MWCO) values between 5,000 and 120,000 Daltons. The membrane selected with this unit has an MWCO of approximately 8,000 Daltons, meaning approximately 90% of all material that passes through the membrane is 8,000 Daltons or smaller, corresponding roughly to a pore size of 0.005 µm. As Figure 1 shows, the membrane will reject bacteria, viruses, and some proteins, but not sugars or aqueous salts[4].

The filters are made by rolling a sheet of membrane with a spacer to create a spiraling tube. This rolled filter fits into standard 20-inch filter housing. Pressurized water is forced in one end of the roll. Because the water flow is parallel to the membrane, also called crossflow, most of the water is passed through unfiltered and returned to the feed tank so that it has another chance to be filtered. The sheering action of the water on the membrane helps to reduce fouling. Figure 2 shows how normal filtration allows more build-up of solids on the membrane surface than crossflow filtration[5]. The filtered water (permeate) is collected in a tube that runs through the center of the roll and is discharged through a small permeate tube.

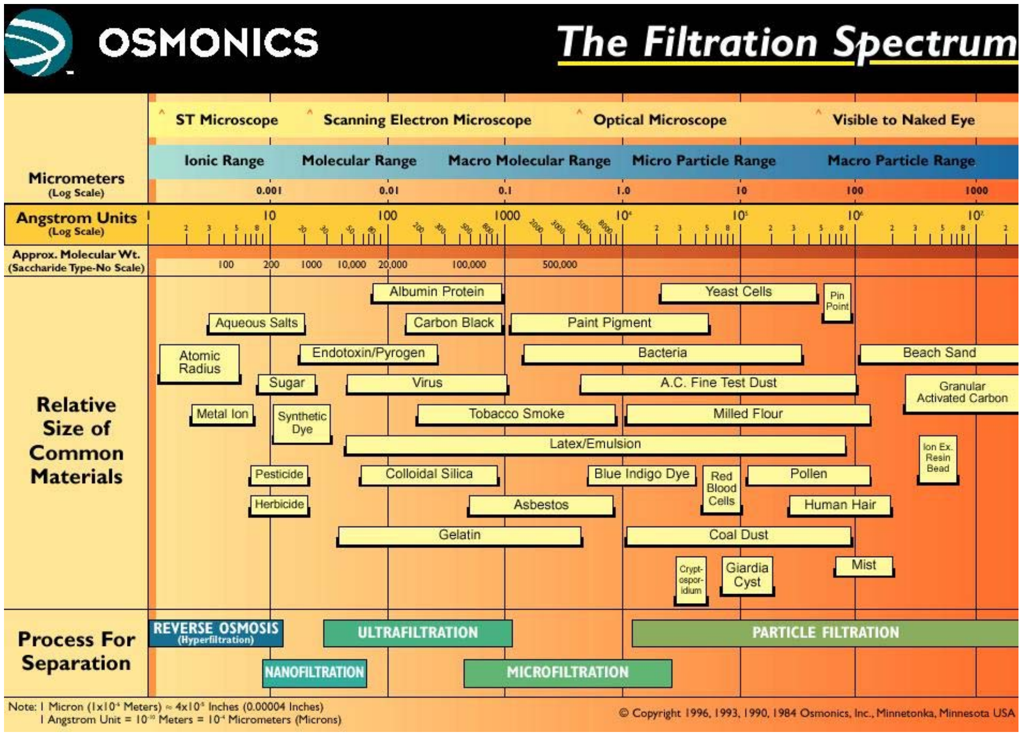

Figure 1. The Filtration Spectrum.

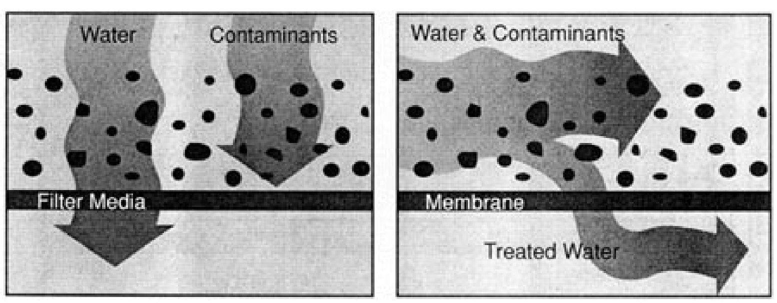

Figure 2. Normal Filtration (left) versus Crossflow Filtration (right).

The Splitter XD, shown in Figure 3, uses two 20-inch membranes in parallel to filter approximately 250-300 gallons per day (gpd). It is equipped with a 1.5 horsepower (hp) centrifugal pump (1120 watts) that operates on 120 volts alternating current (VAC) power. The inlet and recycle ports are equipped with quick disconnect fittings and valves on the supplied hoses. The effluent outlet is also equipped with a ball valve. The front panel features a pressure gauge and a power switch. An onboard logic board performs several safety functions and timed cleaning cycles. Backwashing is not needed; membrane cleaning is performed by pulsing water at high pressures through the membrane. Typically, a specialized membrane cleaner solution is used, but the vendor is confident that the detergent used in the washing process will act as a membrane cleaner. The Splitter weighs 150 lbs, and its overall dimensions are 17in x 22in x 39in.

Figure 3. Infinitex's Splitter XD Ultrafilter.

2.2.2 Bristol International's Tubular Ultrafilter

Bristol International's tubular ultrafiltration system (Figure 4) works on the same principle as the spiral-wound ultrafiltration but in a different configuration. The ultrafiltration membrane is shaped into a 5-foot long tube with a diameter just under 1 inch. The tube is mounted inside a 1in nominal chlorinated polyvinyl chloride (CPVC) tube with a spacer on the outside. As water passes over the membrane, some water and other small molecules are allowed to pass through, while the bulk of the feed passes by. The concentrated feed is returned to the feed tank. The feed is recirculated and concentrated until it is approximately 10% of its original volume. The Bristol International system was initially outfitted with 120,000 Dalton MWCO membranes but was upgraded to 75,000 Dalton MWCO membranes for use in this technology demonstration.

Figure 4. Bristol International's Tubular Ultrafilter with Tank.

2.2.3 Ovation Products' Vapor Compression Distiller

The Ovation Products' vapor compression distiller (VCD) system (also called a microdistillation system) is shown in Figure 5. It uses VCD to achieve high efficiencies. The following excerpt from the Ovation Products' website explains the system and the technology:

Figure 5. Ovation Products' Mechanical Vapor Compression Distiller.

"Mechanical vapor compression-distillation is a well-known, highly refined industrial process. The technique has been applied to many processes for concentration of fluids in such diverse applications including desalination, dewatering of food products (whey, vegetable and juice concentrate), and chemical and petroleum refining. [Figure 6 shows the flow arrangement of a basic vapor compression-distillation process for a dilute water stream.] In operation, steam drawn from the evaporator is compressed, so that it can be condensed at a higher temperature. Droplets of the liquid are separated before entering the compressor. The condensation of the compressed steam occurs in a heat exchanger that transfers the latent heat of vaporization to the incoming water, evaporating additional liquid. The same heat exchanger serves as both an evaporator on one side and condenser on the other. The temperature difference (and associated pressures) between the two streams can be quite small, resulting in very little power input to the compressor. Additional heat is recovered in secondary counter-flow heat exchangers in which the cold incoming water is heated to nearly the same temperature as the outgoing hot streams.

"Nearly all [pre-existing] vapor compression-distillation applications involve very large-scale systems for which the designs are not easily transferred to "appliance type" water treatment systems. In particular, problems of handling and disposing of a dilute wastewater effluent containing suspended solids as well as dissolved gasses and solids are quite considerable on small-scale systems. Ovation's technology deals with these problems in four distinct stages: particulate filtration, degassing, distillation, and final heat recovery. In operation, the incoming water first passes through a 20-micron pre-filtration stage. After being filtered, the incoming

water flows through a highly effective (95%) counter-flow heat exchanger, raising its temperature to above 205°F. Dissolved gases and low temperature boiling point volatiles are vented from the water before entering the evaporator. Also, to limit the build-up of concentrated contaminates in the evaporator, a fraction of the liquid, about 15% of the incoming flow, is continuously discharged to the drain. The evaporating water, at a temperature of 212°F, is compressed to a pressure of 25-40 inches water column (0.9-1.4 psig), an equivalent saturation temperature of 214.5-217°F. At this elevated pressure, the steam condenses as clean condensate. The hot condensate is then cooled down in the counter-flow heat exchanger by the incoming cold water, to nearly 205°F. Based on these operating parameters, the specific distillation energy requirement over the expected operating pressure range is quite low, estimated to be 25-35 W-H/gal." *Source: Ovation Products Corporation, Nashua, New Hampshire*

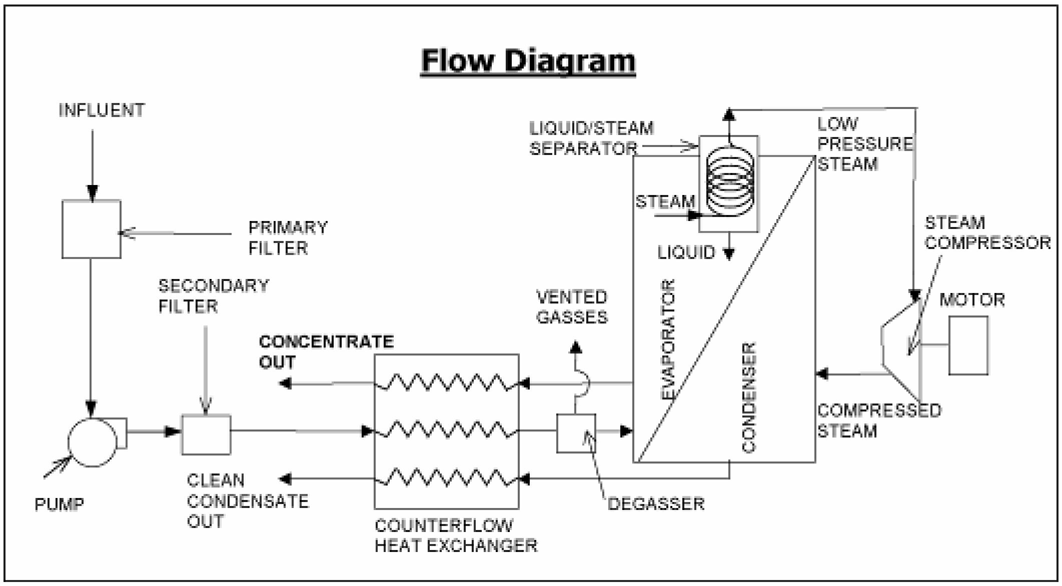

Figure 6. Mechanical VCD Flow Diagram.

Source: Ovation Products Corporation, Nashua, New Hampshire

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Engineers at the Natick Soldier Center (NSC) have tested COTS ultrafiltration systems extensively for this application. Ultrafiltration has been compared to many filtration methods, including oil separation, filter bag media, woven filter cartridges, spin filtration, passive ceramic filtration, and single stage distillation.

Ovation Products is the only company to provide micro VCD as a COTS item. Another New Hampshire company, DEKA, is working on similar technology but is not at a point in their development to offer a system for demonstration. The Ovation Products' microdistillation unit is the first of its kind and the only such unit to be tested at the NSC for this application.

Tests were focused on measuring permeate flow rate, permeate quality, and percent reduction of contaminants. The Infinitex Splitter XD ultrafilter was tested with multiple membranes, including ultrafiltration membranes and nanofiltration membranes.

Each system was tested with simulated greywater made from canned chili con carne, baked beans, vegetable oil, and powdered soap in the proportions shown in Table 1. The food mixture was designed to resemble greywater encountered at previous field tests.

Table 1. Simulated Greywater Recipe.

Ingredient	Per gal	80 gal	110 gal	165 gal
Food Mixture	0.015 L	1.25 L	1.67	2.5 L
Vegetable Oil	5.24 mL	430 mL	577 mL	865 mL
Soap	0.0136 lbs	1.125 lbs	1.5 lbs	2.25 lbs

Table 2 gives an overview of data collected during in-house tests.

Table 2. Average Results from Previous Testing.

System	Permeate Flow Rate (gallons per hour [gph])	BOD (mg/L)	TSS (mg/L)	pH (mg/L)	Oil and Grease (mg/L)	Turbidity (nephelometric turbidity unit [NTU][1])	Comments
Bristol Ultrafilter with 200,000 MWCO tubes	41	200	8.8	10	10.5	5.8	Biological oxygen demand (BOD) too high; decided to increase flow rate for permeate quality
Bristol Ultrafilter with 75,000 MWCO tubes	8.9	190	0	10	5.3	0.2	
Ovation Beta 2	4.8	10.5	0	7.0	0	2.6	Flow rate too slow but good water quality results
Infinitex ultrafilter	8.7	210	12	9.7	4.5	1.8	BOD high, but good turbidity; poor prefiltration contributed to sub-optimal results
Infinitex nanofilter	5.3	7.0	0.0	n/a	0	9.6	Flow rate too low
Ceramic filtration	3.6	200	38	6.9	38	50	Low flow rate, fragile design
Mesh spin-filtration	65	610	230	6.4	16	68	Inadequate filtration

[1] nephelometric turbidity unit

Using these results, the Infinitex Splitter XD spiral-wound ultrafilter, the Bristol International tubular ultrafilter, and the Ovation Products VCD were chosen to be field tested.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Each system has its advantages. Infinitex's Splitter XD, a spiral-wound ultrafiltration device has a very simple construction—its only moving part is a pump. Sized to process 250 gpd, its membranes can remove more than 90% of oil and grease (O&G) and 90% of the total suspended solids (TSS). The effluent is then safe to dump directly on the ground; however, without regulatory approval, it is unclear whether the effluent is fit for recycling or not.

When it is outfitted with comparable membranes, Bristol International's tubular ultrafilter would produce an effluent water quality similar to that produced by the spiral-wound unit; however, due to the low membrane surface area in each tube, a large number of tubes are necessary for an acceptable permeate flow rate, and consequently require a larger pump. To compensate, the Bristol International tubular ultrafilter was outfitted with membranes that have a higher MWCO than the spiral-wound membranes, which allows more water to permeate membrane at a higher rate but, of course, adversely affects the permeate quality. The advantage of the tubular system is that the system requires no prefiltration of the feed due to its large diameter tubes. Large food particles simply pass through the 1-in tubes. The lack of a prefilter means less waste, fewer pumps, and water storage tanks.

The advantage to Ovation Products' VCD is that it outputs almost pure water. This will permit recycling the water back into the wash and rinse sinks. While the existing design is small, the drawback is its weight. At 300 lbs, it is currently twice as heavy as either of the membrane systems and too heavy for field use.

Table 3. Advantages and Limitations of the Technology.

System	Advantages	Limitations
Infinitex Splitter XD Spiral-Wound Ultrafilter	• Simple construction • Few moving parts • Rugged design • Adequate size and weight	• Effluent may not be fit for recycling • Requires prefiltration • Membrane will foul over time • Freezing damages membranes • Drying damages membranes
Bristol International Tubular Ultrafilter	• Simple construction • Few moving parts • Flexible configurations • Prefiltration not required	• Lack of surface area means more tubes or higher MWCO to achieve proper flow • Requires prefiltration • Membrane will foul over time • Freezing damages membranes • Drying damages membranes
Ovation Products VCD	• High-quality effluent	• Too heavy • Not a rugged design • Complex construction

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The objective of this demonstration is to measure the performance of three portable greywater systems when used with Army FSCs and to determine the feasibility of each technology. Performance is measured by reducing the levels of contaminants in the feed water to comply with Environmental Protection Agency (EPA) standards for secondary treated water, as outlined in the Clean Water Act (CWA), the Code of Federal Regulations, 40 CFR 133.102, and in Table 4.

Table 4. Secondary Treated Water CWA, 40 CFR 133.102.

BOD-5 day	(1) The 30-day average shall not exceed 30 mg/L. (2) The 7-day average shall not exceed 45 mg/L. (3) The 30-day average removal shall not be less than 85%.
TSS	(1) The 30-day average shall not exceed 30 mg/L. (2) The 7-day average shall not exceed 45 mg/L. (3) The 30-day average removal shall not be less than 85%.
pH	The effluent values for pH shall be maintained within the limits of 6.0 to 9.0 unless the publicly owned treatment works demonstrates that (1) inorganic chemicals are not added to the waste stream as part of the treatment process and (2) contributions from industrial sources do not cause the pH of the effluent to be less than 6.0 or greater than 9.0.

The parameters tested and their definitions are listed in Table 5.

Table 5. Testing Parameters.

Test	Definition
BOD-5 day	A measure of the amount of oxygen used by aerobic bacteria in a 5-day period to decompose the organic matter in water. An indirect measure of the amount of nutrients in water.
5-day carbonaceous biological oxygen demand (CBOD)	The result of the breakdown of organic molecules such cellulose and sugars into carbon dioxide and water.
Chemical oxygen demand (COD)	Measures the amount of the organic matter in wastewater that can be oxidized (burned up) by a very strong chemical oxidant.
TSS	Concentration of total suspended solids in water
Total dissolved solids (TDS)	Concentration of total dissolved solids in water
O&G	Concentration oils and greases water
pH	A measure of hydrogen or hydroxide ions available in water and given on a 0-10 scale. Numbers under 7 are acidic and above 7 are basic.
Total phosphorous (Tphos)	Concentration of phosphorous in water
Nitrogen, Nitrate/Nitrite (NO_2/NO_3)	Soluble forms of nitrogen that act as nutrients for bacteria, algae, and plants. Too much can cause pollution.
Turbidity	The relative clarity of water that can be affected by suspended and dissolved solids.

Table 6 shows the performance objectives and whether or not each of the systems met each objective. These results differed only slightly from laboratory testing. The only surprise was the failure of Bristol International's tubular ultrafiltration system to retain all the suspended solids.

Table 6. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?		
			Infinitex	Bristol	Ovation
Quantitative	Permeate/effluent quality	<30 mg/L BOD/CBOD	No	No	Yes
		<30 mg/L TSS	Yes	Yes	Yes
		pH 6-9	Yes	Yes	Yes
	Reduction in waste volume	8–10 fold	Yes	Yes	Yes
	Clear water that can be recycled	≤ 5 NTU	Yes	No	Yes
	Permeate flow rate	At least 60 gal of water processed by the next meal	Yes	Yes	Yes
Qualitative	Ease of use	Set-up breakdown by one or two cooks. Operate without monitoring	Yes	Yes	Yes
	Reliability	No breakdowns inherent to the design	Yes	No	Yes

3.2 SELECTION OF TEST SITE

An Army testing facility was selected for the initial demonstration facility because the water treatment system is being designed for use with an Army kitchen and FSC. The initial test site was selected based on convenience, facility support, and intensity of training. Close coordination and cooperation of the hosting facility was heavily weighted, as was the ease of access to the site itself so the numerous and voluminous water samples could be easily transported into and out of the facility. One site that met all of these criteria was Fort Lee, Virginia.

3.3 TEST FACILITY HISTORY/CHARACTERISTICS

Fort Lee's Log Warrior training exercise was chosen for the location of this field demonstration. It is a natural choice for a first test of food equipment as Fort Lee is the home of the Quartermaster School, the combat developer for mobile food service equipment. It also provides a maximum likelihood of success because of its existing infrastructure. The test site includes two large concrete hard stands for the kitchen and the sanitation center, a built-in greywater sump tank with contracted backhaul support, access to a 120V electrical power grid, and port-a-potties.

Because of these amenities, Fort Lee's facilities are not a mirror image of an actual field site, but they provide an excellent first testing ground for items being considered for field use. The cooks are trained to perform functions according to doctrine, a rarity in the ever-changing landscape of the battlefield. This provides a solid baseline from which to work. The Log Warrior training site, while wooded, is not considered very large, and a well-maintained dirt road allows easy access to the kitchen site. A map of the testing site is shown in Figure 7.

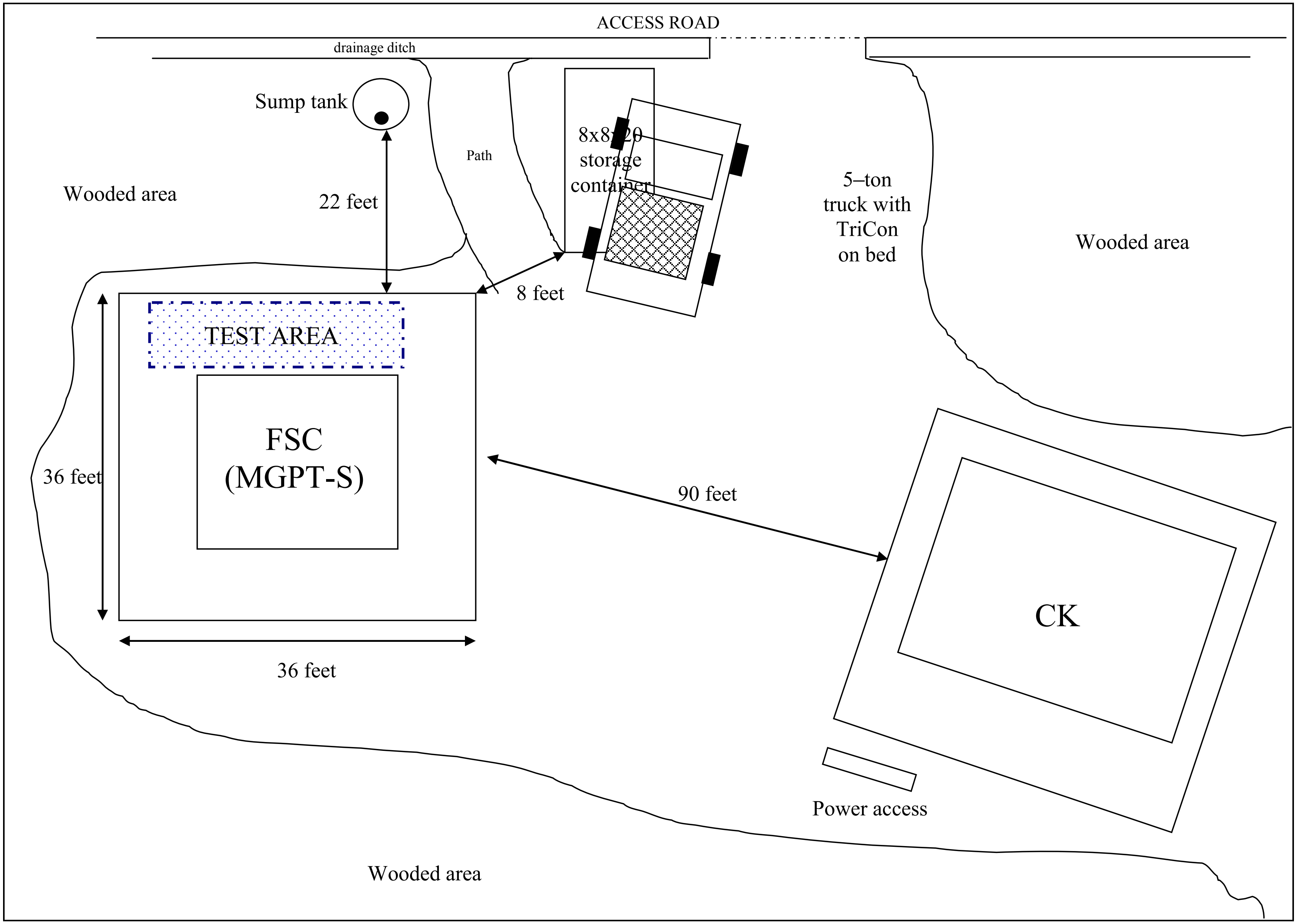

Figure 7. Test Area Layout.

3.4 PHYSICAL SETUP AND OPERATION

The greywater system was incorporated into the sink system as shown in Figure 8. The three sinks hold 20 gallons of water each and are dumped four times per day for a total of 240 gallons. After washing, rinsing, and sanitizing the cookware, the water is dumped into the greywater system. This system, as explained in the following sections, includes not just the greywater filtration device but also the holding tanks, pumps, and plumbing necessary to support the system's operation.

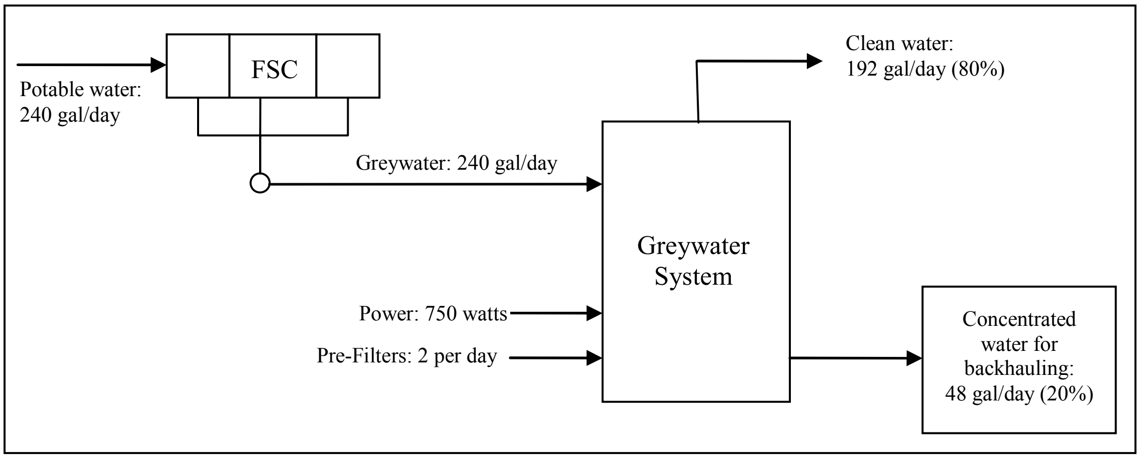

Figure 8. Overall Greywater System Setup.

To reduce the weight, bulk, and complexity of the demonstration, the three systems tested shared many of the same sump pumps, hoses, and tanks. However, due to differences in operation, the setups are not quite the same. For instance, the Bristol International tubular ultrafilter does not require prefiltration; the Ovation Products VCD comes equipped with its own prefiltration system; and the Infinitex prefiltration system was designed in-house. The following sections explain the setup and startup procedures in detail.

3.4.1 Bristol International Setup

The setup schematic is shown in Figure 9. The Bristol International system was set up in the following manner:

The FSC drain hose was connected to a ⅓ hp sump pump, which moved the greywater into a 120-gal tank for sampling and processing. The inlet to the ultrafiltration system was connected to the lower access port on the tank, and the return hose was connected to the top access port. The permeate hose was placed in either 55-gal holding tank for flow measurement

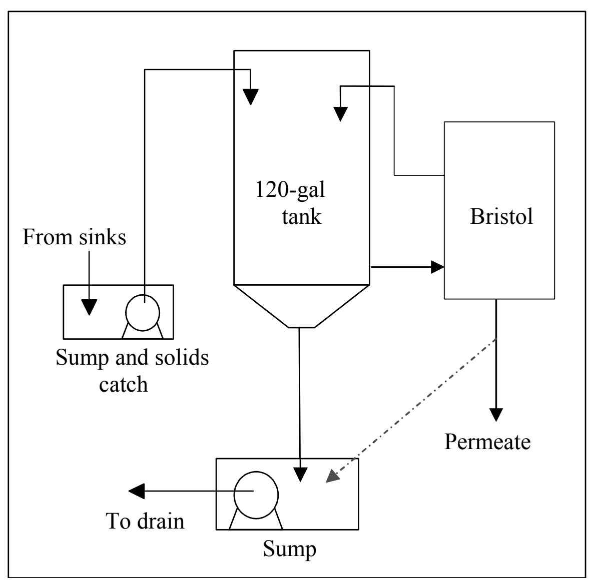

Figure 9. Bristol Setup Diagram.

purposes or into the ⅓-hp sump pump that moved the wastewater to the in-ground sump tank where the wastewater is normally collected. For safety and regulatory purposes, the clean permeate was not recycled as wash water. All electrical connections were made through a single 15-amp circuit via an outdoor power strip.

3.4.2 Ovation Products Setup

The Ovation Products VCD was set up according to the schematic in Figure 10 in the following manner:

An adjustable cart was used to raise the system to a level above the distillate sump tank, or about 2 ft off the ground because the distiller runs on low pressures and lifting it helped to maximize the distillate flow rate out of the unit. The distillate sump was constructed from a 5-gal bucket, a level switch, a Teel aquarium pump, and a control box. This moved the water into a much taller 55-gal drum.

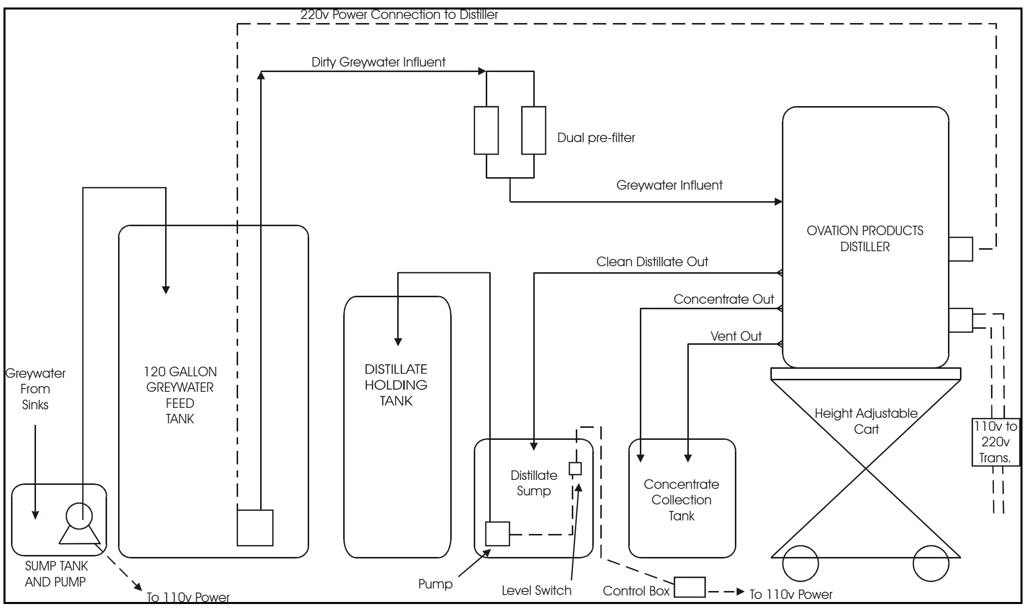

Figure 10. Ovation Setup Schematic.

A second 5-gal bucket served as a condensate and vent collection tank. As shown in Figure 11, the greywater from the sinks entered a sump and was pumped, using a ⅓-hp greywater sump pump, into a 120-gal feed tank where the greywater was mixed, sampled and stored while being fed into the distiller.

A $^{1}/_{12}$-hp Little Giant pump, located in the bottom of the feed tank, delivered greywater through a ⅜-in hose to a set of cotton-wound prefilters (shown in Figure 10 but not Figure 11) that were plumbed in parallel and mounted on a wooden stand. The filtered greywater was fed to the distiller through the "influent" input on the right side of the unit.

Designed for the European market, the Ovation Products VCD and the influent pump ran on 220V power. A 110-220V step down transformer was implemented so that the system could be plugged into an 110V circuit. All other pumps were 110V and plugged into the same circuit via an outdoor power strip.

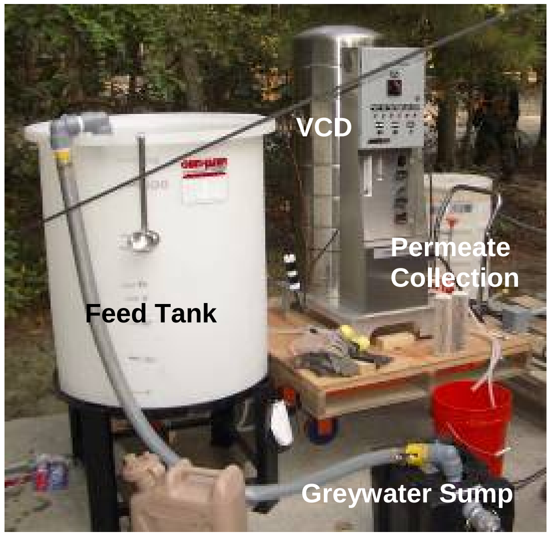

Figure 11. Ovation VCD Setup.

3.4.3 Infinitex Splitter XD Ultrafilter Setup

Figure 12 and Figure 13 show the setup of the Infinitex Splitter XD spiral-wound ultrafiltration system. A ⅓-hp sump pump (sump #1) was used to move the greywater from the sanitation center to a 120-gal wastewater tank so that it could be held for sampling. Raw water samples were taken from this tank.

A second ⅓-hp sump pump (sump #2) was used to direct the feed water through a 50-micron bag filter for prefiltration and into a second 120-gal holding tank. A sample of the prefiltered water was taken from this tank. And as Figure 12 shows, the tank was also used as a feed for the ultrafilter. The ultrafiltration system draws from and recycles the concentrate back to this second tank. The inlet to the ultrafiltration system was connected to the lower access port on the second tank, as shown in Figure 13, while the return hose was connected to the top access port (not shown). The permeate hose was directed to a 55-gallon holding tank (not shown) for sampling purposes.

A third sump pump was used to pump the waste to the inground sump tank where the greywater is normally placed. For safety and regulatory purposes, the clean permeate was not recycled as wash water during this demonstration.

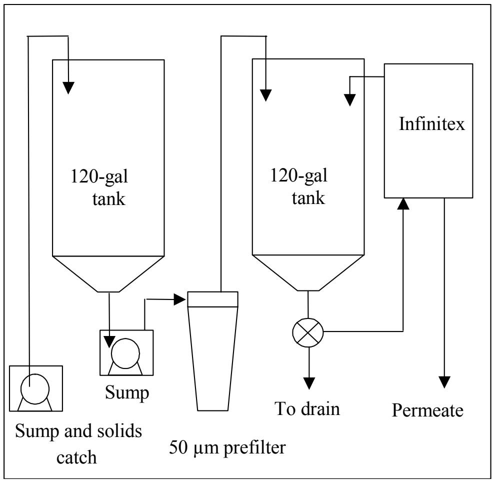

Figure 12. Infinitex Setup Schematic.

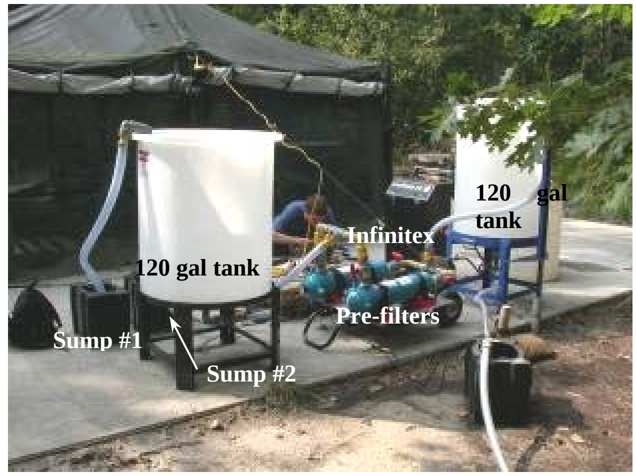

Figure 13. Infinitex Setup.

3.4.4 Period of Operation

The Field Demo Plan[6] stated that each system would operate for a full 4-day Log Warrior exercise, totaling two systems for 2 weeks, seven meals per week. This changed dramatically due to many factors. A third system (Ovation Products) was introduced, as were a second set of filters from Membrane Technology Research (MTR) that were to be tested with Infinitex's Splitter XD ultrafiltration system. This brought the total number of systems to four. The Log Warrior schedule then was reduced to five meals the first week and, due to one day of bad weather, three meals the second week, for a total of only eight meals. The schedule is shown in Table 7. Each of the four systems operated for two consecutive meals with the exception of the Bristol International's tubular ultrafilter, which operated three consecutive meals, and the MTR filters, which saw only one meal.

Improved communication with the Log Warrior organizers could have resulted in better planning, and a more thorough test, but each system did get a chance to be tested.

Table 7. Test Schedule.

		Monday	Tuesday	Wednesday	Thursday	Friday
Week 1	**0500-0900** Leftover from previous night	Arrive at Fort Lee Meet and greet Coordinate logistics to test site	Arrive at test site Move equipment Set up equipment	Bristol	Bristol Int.	Ovation
	0900-1330 Breakfast			Heat and serve breakfast Bristol	UGR-A Breakfast Ovation	MRE
	1330-2100 Dinner		Heat and serve dinner Bristol	unitized group ration (UGR)-A dinner Bristol	UGR-A dinner Ovation	
Week 2	**0500-0900** Leftover from previous night		Log Warrior canceled due to weather (hurricane and tornado)		Infinitex with MTR	
	0900-1330 Breakfast			Set up for evening meal	UGR-A breakfast Infinitex	Pack up Move out
	1330-2100 Dinner			UGR-A dinner Infinitex with MTR	Heat and serve dinner Infinitex	Meet with Fort Lee facilitators and depart

3.5 SAMPLING/MONITORING PROCEDURES

The test was set up as a semibatch process; the feed was the greywater streams from the FSC and containerized kitchen (CK). Greywater is typically disposed of in 60-gal batches by opening valves on the back of each 20-gal sink. Each breakfast and dinner (Meals, Ready-To-Eat [MRE] rations are served for lunch) typically requires two batches of 60 gal, at the rate of one batch per hour. Each test typically began after the first batch, and subsequent batches as necessary, were added to the feed. Changes in feed concentration were monitored. Adding a second batch of greywater to the first significantly changes the chemistry of the feed, so the feed was typically mixed at this point and sampled. Breakfast and dinner operations are separated by approximately 5 hours. There was almost no time to process the water after dinner and before "lights-out," so a portion of the water was left overnight and processed first thing in the morning. As shown in the schedule in Table 7, there were typically 4 hours available for greywater processing before the breakfast sanitation operations began.

3.5.1 Digital Data Sampling

A laptop computer and a Data Translation DT9805 USB Data Acquisition Function Module were implemented to record ambient temperature, bulk feed temperature, permeate temperature, and permeate flow rate every 5 seconds.

The flow meter was powered by a 12V power supply. A portable frequency meter was used to read the digital flow meter. This was due to a hardware incompatibility between the flow meter and the DT9805.

3.5.2 Test Log and Manual Data Collection

Each of the three test engineers kept a log of all events during the 2-week demonstration. Notes were also taken on the food prepared, the amount of dishes cleaned, and the means of maintaining and cleaning equipment. The test log included instantaneous flow rates taken by a handheld frequency meter and feed tank levels. This data was compiled, merged with the digital data, and analyzed.

There are no automated process instruments that determine or track the fouling of membranes or indicate when filters are at the end of their service life, but pressure gauges are included on each system and give an indication as to the performance of the system; for example, low pressure typically indicates fouling while unusually high pressure typically indicates a ruptured membrane. Ovation Products' system is the only system to contain automated process instrumentation. It has safety algorithms in place that monitor and control operating conditions. The ultrafiltration systems have minimal or no automated controls but do shut down automatically if pressure is above or below operating limits.

3.5.3 Water Sampling

The greywater was sampled at each stage of the filtering process. The raw water, the prefiltered water, the permeate water, and the concentrate were all sampled. The raw feed water was homogenized by vigorous stirring and sampled before filtering. Each time a new batch of raw water was added to the feed water, the filtration process was momentarily stopped while the feed was rehomogenized and sampled. Permeate samples were taken as necessary or when system conditions changed.

The sample names were formatted in the following manner:

[system name]_[meal #]_[location code]{sample #}

The location codes were: R = raw feed, P = permeate (or distillate), F = prefiltered and C = concentrate. Example: Bristol 1 R2 would be the second raw feed sample from Bristol International's first meal.

3.6 ANALYTICAL PROCEDURES

Each water sample was tested for the parameters listed in Table 8.

Table 8. Water Quality Testing Methods and Techniques.

Test	Method / Technique
BOD - 5 day	EPA 405.1 / SM 5210B
CBOD - 5 day	SM 5210B
COD	EPA 410.4 / SM 5220D
TSS	EPA 160.2 / SM 2540D
TDS	EPA 160.1 / SM 2540C
O&G - Hexane method	EPA 1664
pH	EPA 150.1
Tphos	EPA 365.2 / SM 4500P-E
Nitrogen, nitrate/nitrite	EPA 353.2 / SM 4500NO3-F
Color	EPA 110.2
Dissolved oxygen	EPA 360.1
Turbidity	EPA 180.1 / SM 2130B

Water quality testing, shown in Table 8, was conducted by Analytics Corporation, 8040 Villa Park Drive, Suite 250, Richmond, Virginia 23228. They were selected because of their location and past performance. Analytics provided greywater testing for a similar Army demonstration at Fort Lee, Virginia in May 1999.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

A list of performance criteria was developed to help identify a greywater treatment system that will meet the requirements of the mission. In addition to producing high quality filtered water, the unit must be lightweight and reliable. Table 9 lists each criterion and categorizes its importance as primary, secondary, or tertiary.

Table 9. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Permeate/effluent quality	Each system should produce effluent that can be safely dumped on the ground; however, the goal is for the water to be recyclable.	Primary
Reduction in waste volume	The system must process 250 gpd. The goal is to produce 90% usable permeate and 10% concentrated waste by volume.	Primary
Clear water that can be recycled	The appearance of the waste water is drastically improved. The turbidity is measured to be low, making the clarity high.	Primary
Permeate flow rate	The permeate flow rate is fast enough to process at least 60 gallons of clean water to use in the sinks at the next meal.	Primary
Ease of use	Can the item be set up by one or two cooks and operated without monitoring?	Primary
Reliability	The system must be fail-safe. Equipment failure should not result in a release of waste to the environment or cause any other hazardous condition that might harm an operator.	Primary
Maintenance	Ultrafiltration will frequently require cleanings with membrane-cleaning solution; frequency is to be determined. Filters will need to be changed. This must be a one-person effort requiring minimal training. Regular maintenance for the VCD system would be to clean and/or replace the prefilters and replace the consumable polymerization solution. Infrequent pump breakdowns in both systems will require a more involved level of training.	Secondary
MANPRINT (MANpower and PeRsonnel INTegration)	Each system must conform to strict human factors. The weight should be light enough for five soldiers to carry as per MIL-STD-1472F[7]. The item should be rugged enough to be considered mobile, and hot surfaces must be clearly marked.	Secondary
Versatility	Dual use is an important feature for the Army but will not be considered a performance criterion for this demonstration.	Tertiary
Scale-up constraints	There are no scale-up issues associated with these technologies	Tertiary

4.2 PERFORMANCE DATA

Table 10 provides a summary of each system's performance. Average values are shown for the permeate water quality, volumetric waste reduction, and weight.

Table 10. Performance Data Summary.

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual—Bristol	Actual—Infinitex	Actual—Ovation
PRIMARY PERFORMANCE OBJECTIVES **Quantitative Criteria**					
Permeate Quality - BOD - TSS - O&G - pH	 ≤ 30 mg/L ≤ 30 mg/L ≤ 30 mg/L 6 ≤ pH ≤ 9	 Secondary treatment See Table 5	Averages 447.3 mg/L 28.4 mg/L 62.2 mg/L 5.8 standard units (SU)	Averages 291.2 mg/L 3.8 mg/L 6.9 mg/L 6.1 SU	Averages 17.3 mg/L 1.4 mg/L 5.6 mg/L 7.0 SU
Reduction in Waste Volume - Filters - Sludge	Disposed as municipal waste - 10% of feed - Backhauled for further treatment	Measured beginning and ending levels – weighed water	23% of feed*	9% of feed	18% of feed*
Clear Water That Can be Recycled - Turbidity	≤ 5 NTU	See Table 5	12.8 NTU	4.7 NTU	2.1 mg/L
Permeate Flow Rate	Fast enough to process before the next batch is needed	Digital flow meter and manual time and water level log	16 gph yes	18 gph yes	23 gph yes
PRIMARY PERFORMANCE OBJECTIVES **Qualitative Criteria**					
Ease of Use	Item can be set up by one or two cooks and operated without monitoring.	Observation	Very easy to set up and use	Moderately easy to set up, easy to use	Involved set-up; easy to use
Reliability	No breakdowns inherent to design	Record keeping	One minor breakdown—required 5 min repair	No breakdowns	No breakdowns
SECONDARY PERFORMANCE OBJECTIVES **Quantitative Criteria**					
MANPRINT	5-man portable	Weight of system < 157 lbs according to Army MANPRINT specs	< 150 lbs	~ 150 lbs	~ 300 lbs

Table 10. Performance Data Summary (continued).

Performance Criteria	Expected Performance	Performance Confirmation Method	Actual—Bristol	Actual—Infinitex	Actual—Ovation
SECONDARY PERFORMANCE OBJECTIVES **Qualitative Criteria**					
MANPRINT	Controls are located in appropriate places, hot surfaces are marked, handles are in proper places, etc.	Observation	Controls are awkward. Tubes are hard to move and manage in current configuration.	Controls are on opposite side of fittings. Access door is awkward.	Too heavy. Needs to be elevated 3 ft for proper use.
Maintenance - Ultrafilter **Maintenance** - VCD	- Use membrane cleaner every 24 hours of run time - Clean process tanks - Replace filters once a year - Clean or replace prefilters before every run - Clean with anti-fouling cleanser every 50 hours of run time - Clean process tanks	Record keeping	Sponge balls were used once; action was not needed Cleaned process tanks	Replaced prefilters before each run Jellylike substance formed on top of the filters; was cleaned off with water after two uses Cleaned process tanks	Replaced prefilters before each run Cleaned process tanks

*Limited by system configuration, not by technology

In terms of water quality, Ovation Products' VCD system performed the best. It was the only system to meet the EPA's secondary treatment standards that were used as a goal for this project. However, the system fell short in many other categories such as weight, ruggedness, and complexity of setup.

The Infinitex Splitter XD ultrafiltration system was the next best performer. It was rugged, lightweight, and simple to use and assemble, but the permeate water quality was worse than expected. Even though the permeate was clear and had a turbidity of only 4.7 NTU, the BOD was almost 10 times higher than the acceptable level of 30 mg/L.

Bristol International's tubular ultrafiltration system performed the poorest. Despite being simple to use and set up, the permeate water quality was very poor, with a turbidity of 12.8 NTU and an average BOD of 447.3 mg/L. The water was yellow in color and had an odor.

In conclusion, the Bristol International system was eliminated, but improvements can be made to the Infinitex and Ovation Products systems to make them ready for field use. The Infinitex system could easily be reconfigured to lay flat, have multiple handles, and a lighter frame. Ovation Products Inc. is currently fabricating a lighter, more durable prototype VCD system that will produce the same quantity and quality of distillate.

The U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM) will be consulted to develop a new set of standards for washing, rinsing, and sanitizing water to allow for greywater recycling in the wash and rinse sinks.

4.3 DATA ASSESSMENT

4.3.1 Permeate Flow Rate

The permeate flow rate is the rate at which the system processes the greywater into clean water. The data was collected in two separate ways—by direct measurement of the flow and by measuring the volume recovered over time.

Incremental and cumulative volume was calculated from the measured instantaneous flow rates and time data. The average flow rate was calculated by plotting the cumulative volume versus time. The slope of the line (volume per unit time) was used as the average flow rate.

The chart in Figure 14 provides an example of this method. Here the flow rate and cumulative volume are plotted together. The fit line for the volume was created using Microsoft Excel's Add Trendline function. The slope of the line can be seen in the upper right corner along with the R^2 value. In this case, even though the flow rate drops from 16.8 gph to 14.0 gph over the 2.6 hr test period, we are able to arrive at an average flow rate of 17.3 gph.

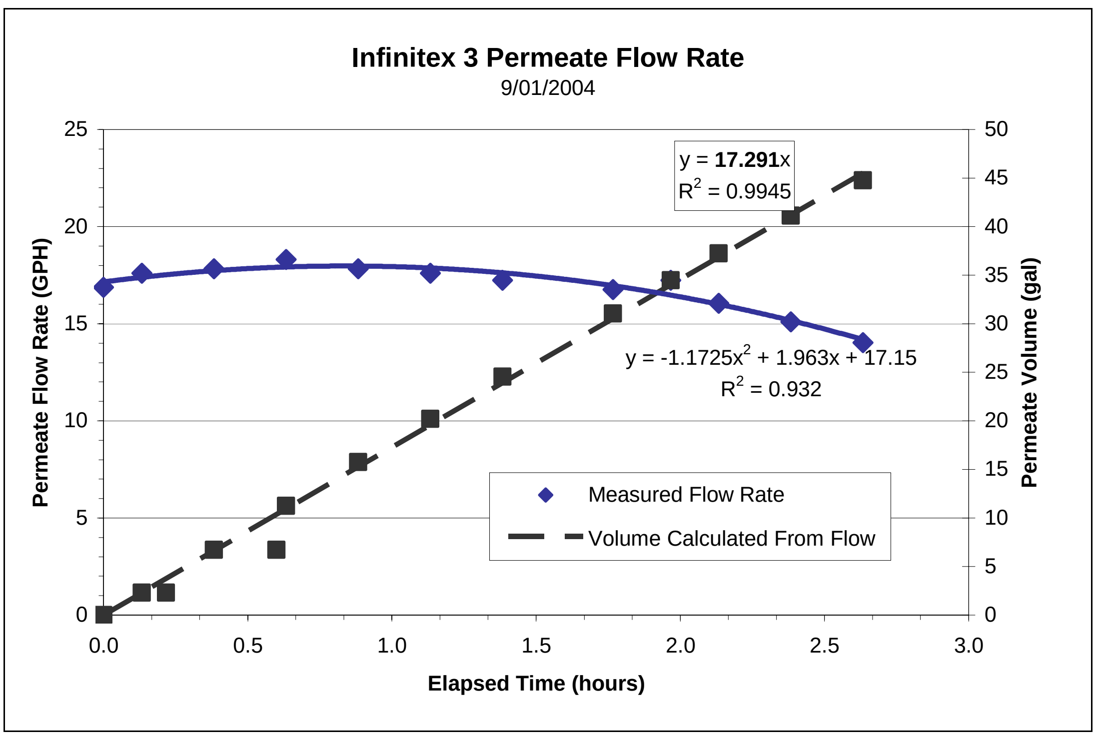

Figure 14. Average Flow Rate Determination for Infinitex's Splitter XD Ultrafilter.

Permeate flow rate was also calculated by marking the level on the 55-gal permeate collection tank with a felt-tip marker after each test. The mark was accompanied by the date, run number, and ending time. The starting time for permeate generation was recorded in a log book. The barrel was taken to the lab after the completion of the test and water was filled to each line and weighed. A volumetric flow rate was calculated from this data.

The results for each run are given in Table 11. Discrepancies between the values cannot be explained, and it is unclear which method is the best in each situation. Fortunately, there is a great deal of permeate flow rate data for each of these systems that was accumulated before this demonstration. Furthermore, none of the systems had any problem filtering all the water before the next meal, which is ultimately the performance requirement.

The results from Bristol 2 P1 are unavailable because of an incompatibility between the flow meter and the data logger. All other flow readings were obtained with a multimeter that read frequency in hertz. The permeate flow rate from the Ovation Products system could not be measured using the flow meter because the flow meter applied too much back pressure on the system and reduced the flow to less than 5 gph.

Table 11. Permeate Flow Rates.

	Method 1	**Method 2**	
	Graphing	**Flow Rate from Weight of Water**	**Average Flow Rate**
Bristol 2 P1	n/a	13.19	13.19
Bristol 3 P2 (left overnight)	11.65	19.02	19.02
Infinitex 1 P1 MTR filters	8.66	7.09	7.09
Infinitex 1 P4 MTR filters	7.58	7.36	7.36
Infinitex 2 P1 Infinitex filters	21.78	16.86	16.86
Infinitex 3 P1 Infinitex filters	17.29	16.53	16.53
Ovation 2 P1	n/a	5.95	5.95
Ovation 2	n/a	28.50	28.50
Total Ovation 2, Day 1	n/a	9.11	9.11
Ovation 2 P2 Thursday morning	n/a	17.78	17.78

4.3.2 Volume Reduction

Each system was required to reduce the overall volume of waste by 85%. This was calculated from the initial and final volumes of water. Occasionally, initial volumes of greywater were not recorded. This posed a challenge in calculating the initial volume from the flow rate and the known waste. Table 12 shows data that is as accurate as possible and a very reasonable scenario.

Table 12. Volume Reductions.

	Start (gal)	Permeate (gal)	End (gal)	% Reduction	Notes
Bristol 1	45	30	15	66.7%	These runs always end with 15 gal due to the configuration of the system
Bristol 2	61	46	15	75.4%	
Bristol 3	90	75	15	83.3%	
Bristol Total	**196**	**151**	**45**	**77.0%**	
Infinitex 1	68.5	63.5	5	92.7%	
Infinitex 2	45	44	1	97.8%	
Infinitex 3	59	49	10	83.1%	
Infinitex Total	**172.5**	**156.5**	**16**	**90.7%**	
Ovation 1	50	44	6	88.0%	The numbers for Ovation 2 have been calculated several different ways from the data and field log. This is the most accurate scenario
Ovation 2	86	76	10	88.4%	
Ovation Total	**136**	**120**	**16**	**88.2%**	

The data shows the Infinitex Splitter XD ultrafilter reducing the waste by 90.7%, the greatest amount. Ovation Products' VCD reduced the volume by 88.2% and the Bristol International tubular ultrafilter by 77.0%. The Bristol International could have reduced the waste by more, but the configuration of the tank was such that 15 gal was always left in the tank after processing. In addition, the ratio of the distillate and concentrate volume can be adjusted on the Ovation Products system. It was set for 90% but missed the mark slightly. This can be more finely tuned in future tests.

Filtration performance is based on both the average contaminant concentration in the permeate stream and the average percent reduction of contaminants. The average and lowest concentrations for each contaminant were recorded for each run, and the percent reduction of each contaminant from the feed was calculated. Percent reduction was calculated for each run using the following equation:

Equation 1: Percent Reduction $$\frac{\text{Raw Greywater Conc.} - \text{Permeate Conc.}}{\text{Raw Greywater Conc.}} * 100$$

Percent reduction characterizes how well the system removed each contaminant and predicts permeate concentrations at any given feed concentration. It can be thought of as the system's filtration efficiency. The overall percent reduction for each system over all runs is shown in Table 13 and graphically in Figure 15.

Table 13. System Performance: Percent Reduction.

Contaminant Name	Bristol	Infinitex	Ovation
TSS	94.5%	98.1%	99.8%
TDS	43.5%	59.7%	83.5%
O&G	45.1%	90.3%	96.3%
BOD	66.1%	78.7%	98.5%
COD	70.5%	71.2%	98.2%
CBOD	64.0%	75.3%	98.7%
Turbidity	88.0%	91.1%	99.4%
Color	35.4%	68.3%	78.5%
Phosphorus	30.5%	66.1%	99.6%
Nitrate-Nitrite	-14.6%	-0.4%	58.8%

Values for pH and dissolved oxygen are left out of the table because percent reduction values do not apply to these values.

As Figure 15 shows, Ovation Products' system was the most effective and removed the highest percentage of each one of the contaminants. The Infinitex system was the second most effective while Bristol International's tubular ultrafilter system was the least effective.

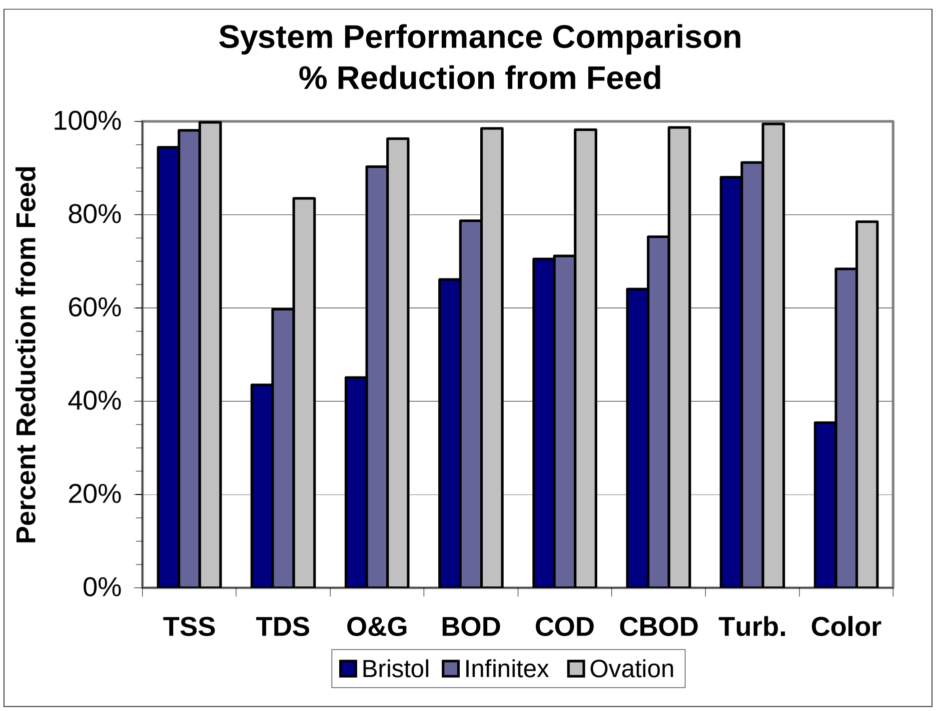

Figure 15. System Performance Comparison.

A similar pattern is revealed when observing the final concentrations for each contaminant in the permeate stream. Table 14 shows the high, low, and average concentrations in the permeate for each contaminant and each system. Consistently producing the highest contaminant levels, the Bristol International tubular ultrafilter system performed the worst in each while the Ovation

Product's VCD system performed the best. The Infinitex system was always somewhere in-between. This is also shown graphically in Figures 16 through 18.

Table 14. High, Low, and Average (AVG) Permeate Concentrations.

		Bristol			Infinitex			Ovation		
		HIGH	LOW	AVG	HIGH	LOW	AVG	HIGH	LOW	AVG
TSS	Mg/L	70.0	2.0	28.4	19.10	0.00	3.82	2.00	1.00	1.37
TDS	Mg/L	690.0	160.0	477.8	548.00	208.00	399.20	245.00	1.00	84.67
O&G	Mg/L	237.7	6.4	62.2	15.00	0.00	6.86	6.90	5.00	5.63
BOD	mg/L	582.0	339.0	447.3	502.00	100.00	291.20	30.00	6.00	17.33
COD	mg/L	1593.0	890.0	1136.5	1660.00	260.00	927.20	97.90	20.00	45.97
CBOD	mg/L	518.0	276.0	390.7	471.00	100.00	277.00	23.00	4.00	13.33
Turbidity	NTU	23.0	1.0	12.9	22.60	0.00	4.72	2.80	1.73	2.13
Color	CU	50.0	5.0	25.0	10.00	0.00	6.00	10.00	5.00	6.67
pH	SU	7.1	4.8	5.8	6.90	5.09	6.10	8.34	4.70	7.03
Tphos	mg/L	8.2	2.5	5.0	3.32	0.13	1.74	0.06	0.02	0.03
NO_2/NO_3	mg/L	0.3	0.1	0.2	1.11	0.00	0.50	0.10	0.10	0.10
Diss O_2	mg/L	8.5	0.6	4.7	5.66	1.52	4.36	1.16	0.74	0.95

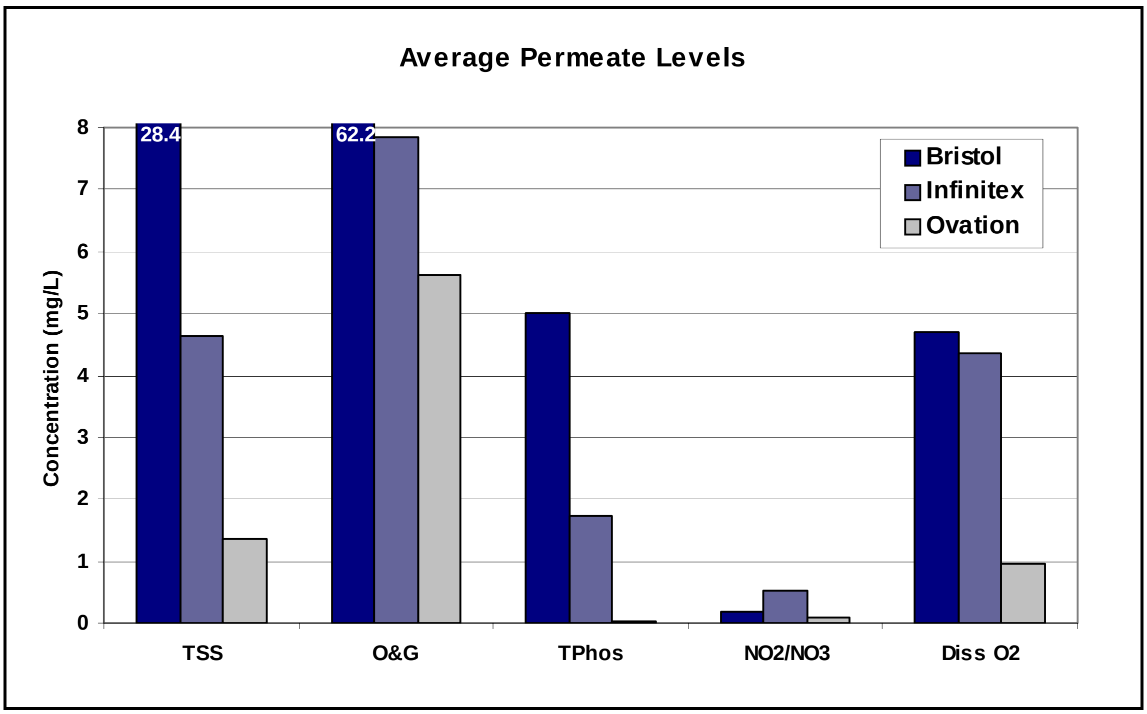

Figure 16. Permeate Levels: TSS, O&G, Tphos, NO2/NOS3, and Diss 02.

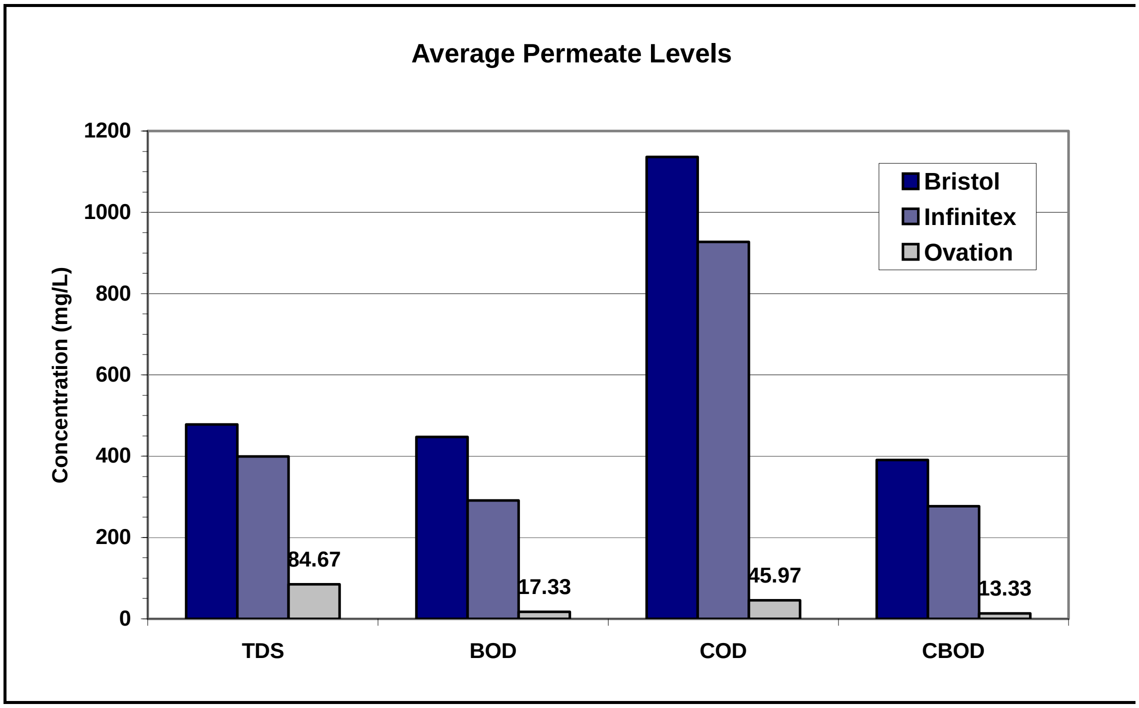

Figure 17. Permeate Levels: TDS, BOD, COD, and CBOD.

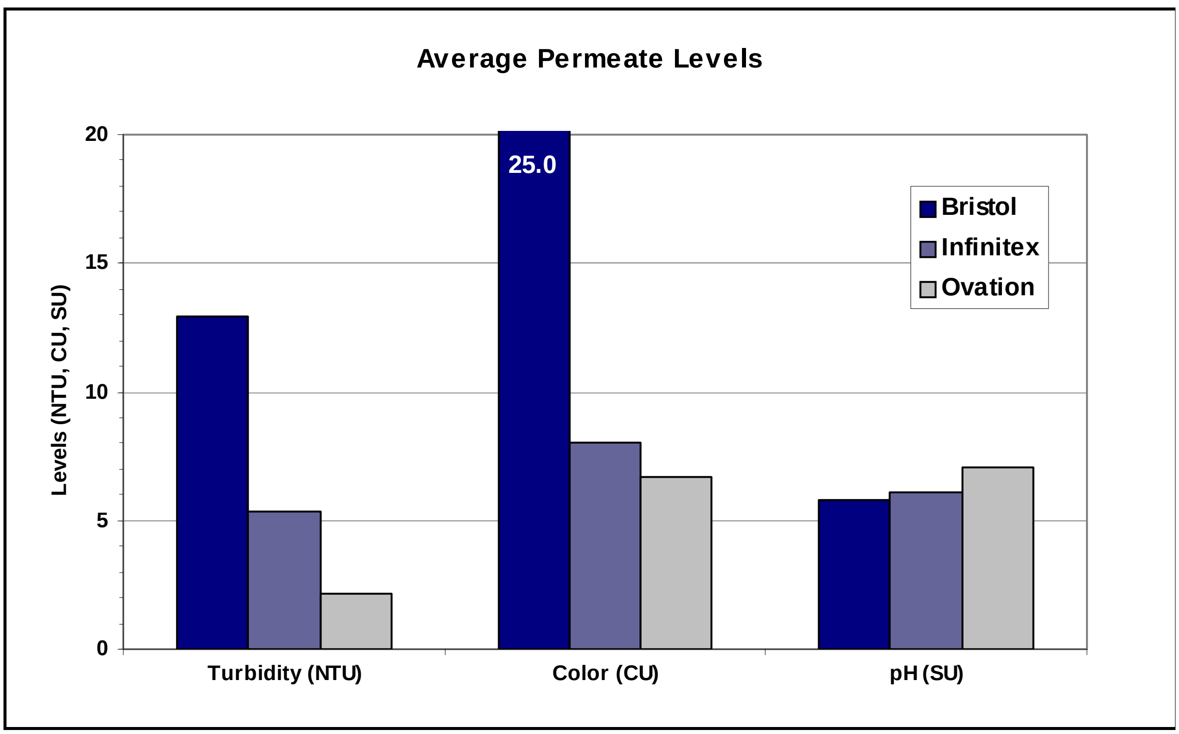

Figure 18. Permeate Levels: Turbidity, Color, and pH.

4.4 TECHNOLOGY COMPARISON

Table 15 and Table 16 compare the performance of each system with the current method of washing dishes in the Advanced Food Sanitation Center (AFSC) without any greywater treatment. This does not take into account the performance of a grease separator, which has yet to be fielded. There is insufficient data on the grease separator's output to report; however, the grease separator certification test, shows grease removal efficiencies of 87% and higher.

Table 15. Technology Comparison.

System	Technology	Weight (lbs)	Permeate Flow Rate (GPH)
Infinitex Splitter XD	Spiral-Wound Ultrafiltration	150 PASS	18 PASS
Bristol International	Tubular Ultrafiltration	150 PASS	16 PASS
Ovation Products	VCD	300 Fail	23 PASS
AFSC	No Treatment Technology	0	0

Table 16. Technology Comparison of Permeate Quality.

System	Permeate Quality					Volume Reduction
	BOD (mg/L)	TSS (mg/L)	O&G (mg/L)	Turbidity (NTU)	pH	
Infinitex Splitter XD	291.2 FAIL	3.8 PASS	6.9	4.7 PASS	6.1 PASS	91 %
Bristol International	447.3 FAIL	28.4 FAIL	62.2	12.8 FAIL	5.8 FAIL	77 %
Ovation Products	17.3 PASS	1.4 PASS	5.6	2.1 PASS	7.0 PASS	88 %
AFSC	1371 FAIL	628 FAIL	220	235 FAIL	7.2 PASS	0 %

While none of the technologies tested met every criterion, Table 15 and Table 16 show that employing any one of them would significantly reduce the amount of BOD, TSS, and O&G in the water.

5.0 COST ASSESSMENT

5.1 COST REPORTING

This cost analysis compares three systems: (1) the AFSC without greywater recycling capability, (2) the AFSC using spiral-wound ultrafiltration as the greywater recycling technology, and (3) the AFSC using VCD to recycle greywater.

The basis for this cost analysis is the AFSC's life-cycle cost estimate (LCCE), which is a detailed life-cycle cost analysis that was performed in preparation for the procurement of 1,329 AFSC systems and was approved by the program manager (PM)—Force Sustainment Systems. Used in the AFSC milestone B decision, this process identified direct and indirect costs associated with the production, fielding, and support of the AFSC in constant FY04 dollars. Most notably, it identified costs associated with the use of potable water and greywater treatment and disposal.

In order to compare each system's operating costs, the entire system is taken into account. For example, the operating cost of the spiral-wound system includes the costs of operating the AFSC as well. However, sunk costs such as AFSC design and procurement costs, are not taken into account because the AFSC will be purchased independent of the greywater recycling system, which will be added on later as a P3I item.

The assessment shows a significant costs savings derived from the savings of potable water and greywater backhauling costs. Because the greywater is recycled for 3 days at a time, the analysis shows more than 50% savings in water. This cost savings is large enough to negate additional procurement, maintenance, and labor costs associated with either of the greywater treatment systems, so much so in fact, that any additional costs, are almost negligible.

Because procurement is expected to span 5 years, the actual operating costs are not estimated to be the same every year. This will be shown in more detail in later sections. The operating costs reported in the simple tables below are for full deployment.

There are also several assumptions defined in section 5.2.1 that were made to arrive at the reported costs.

The following cost tables show the costs associated with the 1,329 AFSC systems that are to be procured.

The P-2 Finance software was used to determine the costs when accounting for the time value of money. The inputs and outputs can be found in Section 5.4.

Table 17. Baseline AFSC Technology Costs.

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operation and Maintenance (O&M)					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing, and fielding	Sunk	Labor to operate equipment	42,533,000	Dumping greywater on ground	Health risk		
Equipment purchase	Sunk	Greywater backhauling	37,677,000				
Installation	Sunk	Fuel	4,254,000				
Training of operators	Sunk	Equipment Maintenance	1,330,000				
		Potable water	25,118,000				
Total	Sunk		**110,912,000**				

Table 18. Spiral-Wound Ultrafiltration Technology Costs.

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		O&M					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing, and fielding	350,000	Labor to operate System	43,998,000	Dumping greywater on ground	0		
Equipment purchase	15,151,000	Greywater backhauling	7,535,000				
Installation	0	Fuel	4,847,000				
Training of operators	100,000	Equipment Maintenance	2,993,000				
Permitting fees	50,000	Potable water	11,152,000				
Delivery	333,000	Prefilters	670,000				
Spare parts	1,515,000	Filters	665,000				
Total	**17,499,000**		**71,860,000**				

Table 19. VCD Technology Costs.

Direct Environmental Activity Process Costs – Ovation				Indirect Environmental Activity Costs		Other Costs	
Start-Up		O&M					
Activity	$	Activity	$/yr	Activity	$	Activity	$
Equipment design, testing and fielding	350,000	Labor to operate equipment	43,998,000	Dumping greywater on ground	0		
Equipment Purchase	15,151,000	Greywater backhauling	7,535,000				
Training of operators	100,000	Fuel	4,847,000				
Permitting fees	50,000	Equipment Maintenance	3,824,000				
Delivery	348,000	Potable water	11,152,000				
Spare parts	2,273,000	Prefilters	670,000				
Total	**18,272,000**		**72,026,000**				

5.2 COST ANALYSIS

The cost analysis was performed using the Environmental Cost Analysis Methodology (ECAM) and the Pollution Prevention (P/2) Finance software. The AFSC's LCCE was used as a baseline for making reasonable assumptions. We then identified all inputs and outputs of the system, developed process flow diagrams, and quantified the resources to arrive at the direct costs. Indirect costs were then identified and quantified to reach an ECAM Level II analysis. The data was then entered into the P/2 Finance software that takes into account taxes, inflation, escalation of the cost of commodities, and depreciation, among other factors.

The analysis is comparing the Ovation Products' VCD system with the Infinitex Splitter XD spiral-wound ultrafiltration system. As the previous section showed, the difference in capital costs between the two systems is minimal. The projected purchase cost of each system is the same because much of the system, including pumps, hoses, water bladders, will be the same.

5.2.1 Assumptions

Tables 20 through Table 22 list the assumptions that were used during the cost analysis.

Table 20. Assumptions Used Throughout the Entire Cost Analysis.

This cost analysis assumes the following:	
1	The greywater treatment system is integrated with the new AFSC.
2	1,329 units will be fielded as a P3I for the new AFSC. This equals the number of new AFSCs to be fielded.
3	When recycling water, the first meal of each deployment uses 100% potable water.
4	The sanitation sink always uses potable water; therefore, a maximum of 100 gal per AFSC per meal can be recycled.
5	Any remaining clean water not used will be dumped (safely) on the ground.
6	The current protocol is to either dump greywater directly on the ground or backhaul it, not both. The percent savings calculated reflects a decrease from each of these options independently.
7	Cost savings is based on recycling greywater for 3 days at a time. At the end of the 3-day deployment, all the water is dumped and the AFSC is filled with fresh water.

Table 21. Assumptions for the AFSC Cost Calculation.

The AFSC O&M support costs were calculated using these assumptions:	
1	Water is estimated at 300 gpd per unit @$0.50/gal. Units will be fielded for 21 days/ six times/year for 126 days/year. Cost per unit per year is $18,900.00.
2	Water disposal is estimated at 300 gpd per unit @$0.75/gal. Units will be operated same as above. Cost per unit per year is $28,350.00.
3	Fuel cost is calculated at 5 gpd for each of three modern burner units (MBU) for a total of 15 gal of JP8 fuel per day. The units will be fielded for 126 days/year. The fuel cost is $1.34/gal; 1,890 gal per unit costs $2,533.00.
4	In addition to the AFSC's LCCE estimate of fuel cost, the AFSC uses a 2kW generator for 6 hours per day, 126 days/year @ 0.66 gal/h, or 498.96 gal/year. The fuel cost is $1.34/gal for $668.60/year/unit. The total AFSC fuel cost is $3201.6/unit/year.
5	Military operators. There are two E-2 operators 6 hours/day times 126 days/year @ $17.49/hour. There is one E-4 supervisor two hours/day times 126 days @ $22.06/hour. Total unit operations labor cost is $32,004/year.
6	Annual maintenance is 45.36 hours for an E-4 @ $22.06/hour or $1001/unit/year.
7	Tents are replaced every 10 years at a cost of $4,750.00 per tent.

Table 22. Assumptions for the Greywater Recycling Cost Calculation.

The greywater O&M support costs were calculated using these additional assumptions:	
1	Capital costs are estimated at $11,400/unit. See Table 29.
2	Prefilter costs are estimated at two filters per day @ $2/filter or $504/unit/year.
3	A set of ultrafilters (two) are replaced every 2 years. This is calculated as 1/year/unit @ $500/filter or $500/unit/year. This cost applies only to the spiral-wound ultrafilter, not the VCD system.
4	Potable water use is estimated at 104.7 gpd per unit @$0.50/gal. Units will be fielded for 21 days/six times/year for 126 days/year. Cost is $6,596.10/unit/year.
5	Water disposal is estimated at 60 gpd per unit @$0.75/gal. Units will be operated same as above. Cost per unit per year is $5,670.
6	Fuel costs: The 2-KW generator is used for an extra 4 hours per day @ 0.66 gal/h, or 2.64 gpd @ $1.34/gal for a cost of $3.54/day/unit, or $445.74/year/unit. This is added to the AFSC's total fuel cost for a total of $3647.34/unit/year
7	Labor costs are military operators. There is one E-2 operator for an extra 0.5 hours/day times 126 days/year @ $17.49/hour. The subtotal unit labor cost per year is $1,101.87/year. This is added to the AFSC's labor cost for a total of $33,105.87/unit/year.
8	Estimate .03 hours of maintenance actions for each operational hour @ 15 operational hours per day, or 0.45 hours/system/day. For 126 days per year, that is 56.7 hours/system/year. At $22.06 per hour, composite standard rate for E-4 soldier, that is $1,250.80/system/year Maintenance operations include cleaning, performing PMCS, and replacing assembly components. The operator will be responsible for care and cleaning of the greywater system. Hourly composite rate obtained online from Defense Technical Information Center (DTIC) at www.dtic.mil/comptroller/rates/2005.

Table 23. Additional Assumptions for VCD Cost Calculation.

The greywater O&M support cost were calculated using these additional assumptions:	
1	VCD system capital costs are estimated at $11,904/unit. See Table 29.
2	The VCD system does not require filters or replacement filters.
3	Prefilter costs are estimated at two filters per day @ $2/filter or $504/unit/year.
4	Assume the annual maintenance required for each greywater treatment system is $1,876.20 based on 85.05 hours at $22.06 per hour composite standard rate for E-4 soldier. Estimate .045 hours of maintenance actions for each operational hour @ 15 operational hours per day. The VCD system is expected to require more maintenance than the ultrafiltration system.

5.2.2 Flow Diagrams

The first step in the ECAM process is to identify the process and its waste streams using flow diagrams. The following diagrams depict the current sanitation system and the proposed system of recycling water back into the wash and rinse sinks of the AFSC. Figure 19 shows that all three of the sinks currently drain to a grease separator which removes oil, grease, and fat from the water. This doesn't reduce the overall volume of the water disposed, nor does it clean the water enough to be disposed of on the ground. The proposed concept is shown in Figure 20. Here, the water is pumped to a greywater treatment system and back into the sanitation sinks. The recycled water is used only in the first and second sinks. Fresh, potable water is always used in the sanitizing sink for proper sanitation.

Figure 20 shows the volumetric flow rates for each stream according to the AFSC LCCE; 300 gpd of potable water is added to the system and converted to greywater. Of this added water, 80% is cleaned for reuse while 20% is unusable concentrate that requires backhauling. Not all the clean water can be used, however, up to 40 gallons of cleaned greywater could be discharged to the ground. This practice, however, would not cause environmental harm or be unsanitary due to the quality of the water.

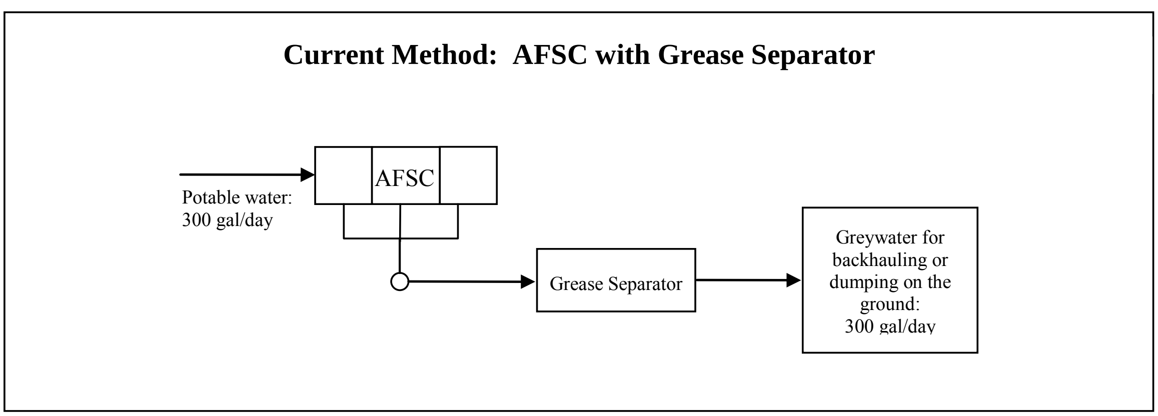

Figure 19. Flow Diagram of Current Sanitation.

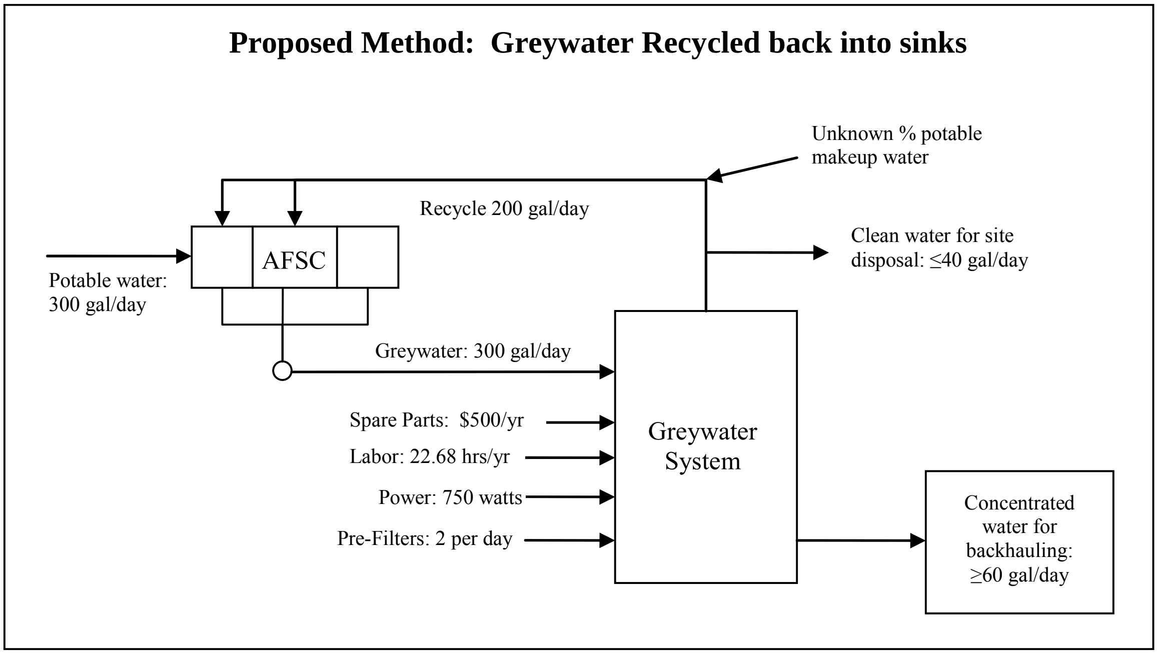

Figure 20. Flow Diagram of Greywater Recycling.

5.2.3 Water Savings Analysis

The amount of water saved by recycling will be determined by the number of consecutive days of deployment. The first meal of the deployment will require the sinks to be initially filled with potable water, and the last meal of the deployment will require the disposal of all the water.

Equations were developed that describe the amount of potable water used, dirty water backhauled, and clean water dumped on the ground. The current practice was determined by the estimate published in the AFSC LCCE which estimates each system uses 300 gpd of potable water and disposes of 300 gpd of greywater. Water usage is variable with a high end of 250 gallons ±20%. These equations were entered into an Excel spreadsheet that uses the length of deployment in days as the independent variable.

Equation 2 $$H_2O_{Used} = 200 + 100(x - 1)$$

Equation 3 $$Backhauled = 60x$$

Equation 4 $$Dump = 140 + 40(x - 1)$$

Where: x = number of consecutive days of use
H_2O_{Used} = gal of potable water used
Backhauled = gal of concentrate for backhauling
Dump = gal of remediated water safe to dump on the ground

The application of these equations, as shown in Table 24, show that the water savings increases with the number of days the water is recycled; however, there are diminishing returns that approach 66% percent savings. There is a decrease of potable water consumption of 55.6% after 3 days, 61.9% after 7 days, 64.3% after 14 days, 65.1% after 21 days, and 65.6% after 30 days.

Table 24. Savings of Water at Various Deployment Lengths.

	Percent Reduction of Volume		
Days of deployment	**Potable Water Saved**	**Greywater Backhauled**	**Greywater Dumped on Ground**
3	55.6%	80%	75.6%
7	61.9%	80%	81.9%
14	64.3%	80%	84.3%
21	65.1%	80%	85.1%
30	65.6%	80%	85.6%

Even though the AFSC LCCE estimates deployments of 21 days, percent savings values were calculated using the more conservative deployment duration of 3 days because the squad usually "jumps" to a new location every 3 days.

For the purposes of this estimation, water costs are represented per gallon and it is assumed that volumetric reductions translate directly into cost reductions. It is outside the scope of this study to perform a detailed logistical study that would take Mission, Enemy, Terrain, Troops & Time Available (METT-T) variables into account.

5.2.4 Resource Consumption and Costs

This section attempts to encompass all direct and capital costs of the proposed system, including water, disposal, fuel, labor, spare parts, and system components. The savings are realized in the drastic reduction of water used and water disposal costs. The values below, as in the previous section, are based on the values published in the AFSC LCCE.

The quantities of each of the resources used in each of the systems are listed in Table 25. The numbers of gallons of greywater treated and dumped on the ground are shown to be equal because, in any given situation, greywater could be discharged to the ground either by accident (collection tank full) or by standard operating procedure (SOP). All values shown are relative to a greywater treatment system.

Table 25. Resource Consumption Table.

1,329 Units	Estimated Annual Quantity		
Resource	Current Method	Ultrafiltration	VCD
Potable water	50,236,200 gal	22,304,000 gal	22,304,000 gal
Greywater treatment	50,236,200 gal	10,047,240 gal	10,047,240 gal
Greywater dumping (on ground)	50,236,200 gal	12,257,633 gal	12,257,633 gal
Fuel	3,174,822 gal	3,617,164 gal	3,617,164 gal
Labor for operations	1,764 man-hrs/unit	1,890 man-hrs/unit	1,890 man-hrs/unit
Labor for maintenance	45.36 hr/unit	102.06 hr/unit	130.41 hr/unit
Prefilters	0	334,908 filters	334,908 filters
Filters	0	1,329 filters	0 filters

Potable water and greywater treatment costs are variable, as explained in section 5.2.6. In Table 26 and in the AFSC LCCE, the highest values are used. Costs could be associated with the health issues related to dumping greywater to the ground; however, this is outside the scope of this cost analysis.

Take note that Table 26 shows the cost of two separate scenarios, either dumping the greywater on the ground or backhauling the greywater for proper disposal. In reality, both scenarios are taking place at the same time.

Table 26. Direct Process Costs (Current Process).

Resource	Annual Quantities Used And Cost Factors		Annual Cost of Dumping	Annual Cost of Backhauling
Potable water	50,236,000 gal	$0.50/gal	$25,118,000	$25,118,000
Greywater treatment	50,236,200 gal	$0.75/gal	N/A	$37,677,000
Greywater dumping (on ground)	50,236,200 gal	N/A	Heath issues	N/A
Fuel	3,174,822 gal	$1.34/gal	$4,254,000	$4,254,000
Labor for operation	2,344,000 man-hrs	$18.14/man-hr	$42,533,000	$42,533,000
Labor for maintenance	60,290 man-hrs	$22.06/hour	$1,330,000	$1,330,000
Total	----	----	**$73,235,000 + health issues**	**$110,912,000**

Table 27. Direct Process Costs (Spiral-Wound Ultrafiltration Process).

Resource	Annual Quantities Used And Cost Factors		Annual Cost
Potable water	22,304,000 gal	$0.50/gal	$11,152,000
Greywater treatment	10,047,240 gal	$0.75/gal	$7,535,000
Greywater dumping (on ground)	7,485,194 gal	N/A	No health issues
Fuel	3,617,164 gal	$1.34/gal	$4,847,000
Labor for operation	2,511,810 hours	$17.51/man-hr*	$43,998,000
Labor for maintenance	135,637 man-hrs	$22.06/hour	$2,993,000
Prefilters	2 per unit/day	$2/filter	$670,000
Ultrafilters	1 /unit/year	$500/filter	$665,000
Total	----	----	**$71,860,000**

*See assumptions for actual labor unit cost breakdown.

Table 28. Direct Process Costs (VCD Process).

Resource	Annual Quantities Used And Cost Factors		Annual Cost
Potable water	22,304,000 gal	$0.50/gal	$11,152,000
Greywater treatment	10,047,240 gal	$0.75/gal	$7,535,000
Greywater dumping (on ground)	7,485,194 gal	N/A	No health issues
Fuel	3,617,164 gal	$1.34/gal	$4,847,000
Labor for operation	2,425,413 hours	$18.14/man-hr*	$43,998,000
Labor for maintenance	173,345 man-hrs	$22.06/hour	$3,824,000
Prefilters	2 per unit/day	$2/filter	$670,000
Ultrafilters	N/A	N/A	$0
Total	----	----	**$72,026,000**

*See assumptions for actual labor unit cost breakdown.

5.2.5 Capital Costs

The cost of the ultrafiltration system is estimated to be equal to that of the VCD system, approximately $10,000 each. There will be one system procured for each new AFSC procured, totaling 1,329 units; however, there is a possibility for a larger market because the AFSC will not replace all 3000+ FSCs currently in service, and greywater recycling systems could be procured for those systems as well. The conservative quantity of 1,329 is used for this study.

Table 29. Capital Costs.

Item	Cost Per Unit	Number of Units	Total Cost
Greywater treatment system	$10,000	1,329	$13,290,000
Clean water bladder	$600	1,329	$797,400
Greywater bladder	$600	1,329	$797,400
Hoses and connectors	$200	1,329	$265,800
Total	**$11,400**	**1,329**	**$15,150,600**

5.2.6 Variable Costs

The extent of the monetary savings from a reduction in potable water and greywater treatment is dependent on several variable costs, including potable water costs, greywater treatment costs, the amount of potable water required, fuel costs, and other METT-T factors. This particular study disregards complex logistical variables such as fuel and METT-T.

This cost model was designed to calculate costs based on three variables: the volume of water used, the cost per gal of potable water, and the cost per gal of disposal of greywater. Table 30 shows the cost boundaries of each of the three variable costs and the percent of uncertainty within each variable.

Table 30. Variable Costs.

Variable Cost	Low Value	High Value	% Uncertainty
Water usage (gal)	200	300	20%
Cost of water (per gal)	$0.03	$0.50	88.6%
Cost of disposal (per gal)	$0.10	$0.75	76.4%

Table 31 shows the impact of the variable costs. Eight scenarios are calculated at the low and high cost boundaries of potable water and waste disposal. As the cost of water and disposal increases, so will the cost savings because recycling greywater reduces the amount of water and disposal at a flat rate. For example, the first box shows a scenario where the AFSC, without the benefit of recycling, uses 200 gpd; the cost of potable water is $0.03 per gallon; and the cost of disposal is $0.10 per gallon. In this scenario, the Infinitex Splitter XD ultrafiltration system is not cost effective, costing an average of $2.1 million per year for 25 years. The Ovation Products VCD system is also not cost effective, costing about $2.3 million per year for 25 years to operate. These numbers do *not* account for inflation, the time value of money, or depreciation; they only show the effect of changes in variable costs. See Section 5.4 for the costs associated with the time value of money.

However, when calculating the savings using the estimated costs and quantities found in the AFSC LCCE, as seen in the lower right hand corner of Table 31, the greywater recycling system will **save an average of $32 million per year for 25 years.**

Table 31. Yearly Savings Depending on Cost Variable Extremes.

		Potable/Disposal $0.03/$0.10	Potable/Disposal $0.50/$0.10	Potable/Disposal $0.03/$0.75	Potable/Disposal $0.50/$0.75
200 gpd	Infinitex	($2,131,054)	$5,220,471	$12,497,728	$19,849,253
	VCD	($2,375,889)	$4,975,637	$12,252,893	$19,604,418
300 gpd	Infinitex	($771,140)	$10,256,148	$21,172,032	$32,199,320
	VCD	($1,015,975)	$10,011,313	$20,927,197	$31,954,485

5.3 COST COMPARISON

5.3.1 Reduction of Logistics and Greywater Disposal

Both of the technologies presented will reduce the cost of water and offsite wastewater treatment significantly enough to offset the costs of development, procuring, fielding, operating, and maintaining the technology in the field. The reduction in logistics is the result of the reduction in potable water consumption by more than 50%.

5.3.2 Cost Differences

According the cost analysis, the difference in cost savings between spiral-wound ultrafiltration and VCD will be minimal. Each unit costs the same and will require the same amount of capital equipment, such as water tanks, bladders, pumps, prefilters, and hoses. Table 25 shows that the VCD system will be slightly cheaper due to the fact that it doesn’t require the purchase or replacement of ultrafilters. This increases the apparent cost savings by $665,000 per year.

5.3.3 Replacement Parts

Spare parts for the spiral-wound ultrafiltration system were estimated as 10% of the capital costs. This mirrors the estimate in the AFSC's LCCE. The more complex VCD system is estimated to require spare parts totaling 15% of the system's capital costs.

5.4 P-2 FINANCE SOFTWARE ANALYSIS

The assumptions and figures reported in sections 5.1 through 5.3 were input into the P-2 Finance spreadsheet using a discount rate of 7%, a study period of 15 years, and a straight-line depreciation method. The salvage value for the equipment was estimated to be 1% of the capital cost. Fuel costs were estimated to escalate 15% per year. Evidence of this was supported by historic costs of #2 diesel fuel in the U.S. as reported on the U.S. Department of Energy website, http://tonto.eia.doe.gov/oog/info/wohdp/diesel.asp [8]. The inputs and outputs of the software are shown on the following 12 pages. The internal rate of return was estimated to be 417% for the spiral-wound ultrafilter and 420% for the VCD.

P2/FINANCE Title-pg1
Version 3.0

09/26/2005

PROJECT TITLE: Greywater Recycling

PREPARED BY: Chad Haering

ORGANIZATION: EET, CFD, NSC, RDECOM

COMMENTS: Assumptions:

1. Discount Rate = 7%
2. Study Period = 15 years
3. Greywater Backhaul Stream Reduced by 85%
4. Equipment Purchase Cost = $10,000 per unit
5. Equipment Installation/Implementation Cost = $0

P2/FINANCE

Pollution Prevention Financial Analysis
and Cost Evaluation System

Version 3.0

Tellus Institute
Boston, MA

09/26/2005

DEFAULT PARAMETERS

Analysis Name: Greywater Recycling 09/26/2005 Default-pg1

Global Parameters

P2/FINANCE uses the Inflation Rate, Discount Rate, and Income Tax Rate entered here for calculations on the Tax Deduction Schedule, Incremental Cash Flow Analysis, and Incremental Profitability Analysis sheets.

Inflation reflects the overall rate at which you expect prices to increase. For cases in which this Inflation Rate does not fully capture expected price changes, P2/FINANCE allows you to define an additional Escalation Rate for each Annual Operating Cost category.

Inflation Rate: 0.0%

The Discount Rate accounts for the fact that there is an opportunity cost to using money -- if you choose to invest in one project, you lose the opportunity to gain a return on another investment. Many companies use their weighted average cost of capital as a Discount Rate. For more information on Discount Rate and its relationship to inflation, see the on-line help.

Discount Rate: 7.0%

State and local income taxes are deductible from the taxable income used to calculate federal taxes. Enter your Local, State, and Federal Income Tax Rates below, and P2/FINANCE will calculate an Aggregate Income Tax Rate.

Local Income Tax Rate	
State Income Tax Rate	
Federal Income Tax Rate	
Aggregate Income Tax Rate	0.0%

The Default Parameters entered by the user in this section can be applied to the entire project file by pressing the button below. __Do not press this button__ unless you are sure that you want these values to apply to the __entire project file__!

P2/FINANCE uses the Depreciation Method and Period entered here as defaults for all Initial Investment Costs. You can change the Depreciation Method and Period for individual categories on the Initial Investment Costs sheet.

Depreciation Method	sl
Depreciation Period	15.0

To specify Depreciation Method, use these abbreviations:

Straight Line	SL
150% Declining Balance switching to Straight Line	1.5DB
200% Declining Balance switching to Straight Line	DDB or 2DB
Expensed (tax deductible in the first year)	EXP
Working Capital (not tax deductible)	WC

The Default Parameters entered by the user in this section can be applied to the entire project file by pressing the button below. __Do not press this button__ unless you are sure that you want these values to apply to the __entire project file__!

Scenario Parameters

P2/FINANCE allows you to create two alternative financial analysis scenarios, which represent different investment options you are considering. You can also create a baseline scenario, which contains data on your current "business-as-usual" operations. On the Incremental Cash Flow Analysis and the Incremental Profitability Analysis sheets, the Alternative Scenarios are compared to the Base Scenario, i.e., P2/FINANCE calculates incremental cash flows and profitability.

The Investment Year and Lifetime entered here are used as defaults for both Initial Investment Costs and Annual Operating Costs. P2/FINANCE assumes that investments occur AT THE END OF THE INVESTMENT YEAR, so the default Start Year for Annual Operating Costs is Investment Year + 1. The most common Investment Year will be Year 0, i.e., most initial Investment Costs are incurred at the very beginning of the project lifetime.

Alternative Scenario 1

Name: Using Ultrafiltration

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

Alternative Scenario 2

Name: Using VCD

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

Base Scenario

Name: Disposal of Greywater by Backhauling

Inv. Year	0	Lifetime	15
Start Year	1	End Year	15

INITIAL INVESTMENT COSTS - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration 09/26/2006 Inv-Alt1-pg1

Initial Investment Costs	$ Amount	Initial Investment Costs	$ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	0
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$1,927,000
Delivery Charges			$42,394
Spare Parts			$192,700
Fielding support (3% of unit cost)			$57,810
Salvage Value	$19,270	TOTAL	$2,219,904

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Electricity			
Steam			
Water			
Fuel			
Plant Air			
Inert Gas			
Refrigeration			
Sewerage			
General Plumbing			
Salvage Value		TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house Planning			$70,000
In-house Engineering/Design			
Procurement			$80,000
Vendor/Contractor Fees			$100,000
Field Testing			$100,000
Salvage Value		TOTAL	$350,000

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Demolition & Clearing			
Old Equipment/Rubbish Disposal			
Grading/Landscaping			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$10,000
Process/Equipment Training			$20,000
Vendor/Contractor Fees			$70,000
Salvage Value		TOTAL	$100,000

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			$50,000
Permit Fees			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$50,000

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Working Capital			$6,478,416
Salvage Value		TOTAL	$6,478,416

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

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Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	1
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	2
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	3
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	4
Dep. Period	15.0	Lifetime	15
Capitol Equipment Costs			$3,306,000
Delivery Charges			$72,732
Spare Parts			$330,600
Fielding support (3% of unit cost)			$99,180
Salvage Value	$33,060	TOTAL	$3,808,512

INITIAL INVESTMENT COSTS - Alternative Scenario 2

Alternative Scenario 2: Using VCD | 09/26/2006 | Inv-Alt2-pg1

Initial Investment Costs | $ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Capitol Equipment Costs	$1,927,000
Delivery Charges	$44,321
Spare Parts	$289,050
Salvage Value: $19,270 — TOTAL	$2,260,371

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Electricity	
Steam	
Water	
Fuel	
Plant Air	
Inert Gas	
Refrigeration	
Sewerage	
General Plumbing	
Salvage Value: — TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
In-house Planning	$70,000
In-house Engineering/Design	
Procurement	$80,000
Vendor/Contractor Fees	$100,000
Field Testing	$100,000
Salvage Value: — TOTAL	$350,000

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
In-house	
Demolition & Clearing	
Old Equipment/Rubbish Disposal	
Grading/Landscaping	
Equipment Rental	
Vendor/Contractor Fees	
Salvage Value: — TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
In-house	
Equipment Rental	
Vendor/Contractor Fees	
Salvage Value: — TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
In-house	$10,000
Process/Equipment Training	$20,000
Vendor/Contractor Fees	$70,000
Salvage Value: — TOTAL	$100,000

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
In-house	$50,000
Permit Fees	
Vendor/Contractor Fees	
Salvage Value: — TOTAL	$50,000

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Salvage Value: — TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	4

Initial Investment Costs	$ Amount
Working Capital	$6,588,309
Salvage Value: — TOTAL	$6,588,309

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Salvage Value: — TOTAL	$0

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Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	1
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Capitol Equipment Costs	$3,306,000
Delivery Charges	$76,038
Spare Parts	$495,900
Salvage Value: $33,060 — TOTAL	$3,877,938

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	2
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Capitol Equipment Costs	$3,306,000
Delivery Charges	$76,038
Spare Parts	$495,900
Salvage Value: $33,060 — TOTAL	$3,877,938

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	3
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Capitol Equipment Costs	$3,306,000
Delivery Charges	$76,038
Spare Parts	$495,900
Salvage Value: $33,060 — TOTAL	$3,877,938

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	sl	Investment Year	4
Dep. Period	15.0	Lifetime	15

Initial Investment Costs	$ Amount
Capitol Equipment Costs	$3,306,000
Delivery Charges	$76,038
Spare Parts	$495,900
Salvage Value: $33,060 — TOTAL	$3,877,938

INITIAL INVESTMENT COSTS - Base Scenario

Base Scenario: Disposal of Greywater by Backhauling 09/26/2005 Inv-Base-pg1

Initial Investment Costs	$ Amount	Initial Investment Costs	$ Amount

Purchased Equipment (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Process Equipment			
Storage and Materials Handling Equipment			
Safety/Protective Equipment			
Monitoring/Control Equipment			
Laboratory/Analytical Equipment			
Spare Parts			
Salvage Value		TOTAL	$0

Utility Connections/Systems

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Electricity			
Steam			
Water			
Fuel			
Plant Air			
Inert Gas			
Refrigeration			
Sewerage			
General Plumbing			
Salvage Value		TOTAL	$0

Planning/Engineering (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house Planning			
In-house Engineering/Design			
Procurement			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Site Preparation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Demolition & Clearing			
Old Equipment/Rubbish Disposal			
Grading/Landscaping			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Construction/Installation (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Equipment Rental			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Start-up/Training (Labor, Materials)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Trials/Manufacturing Variances			
Process/Equipment Training			
Safety/Environmental Training			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Permitting

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
In-house			
Permit Fees			
Vendor/Contractor Fees			
Salvage Value		TOTAL	$0

Buildings & Land

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Working Capital

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Contingency

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

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Purchased Equipment Year 1 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Purchased Equipment Year 2 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Purchased Equipment Year 3 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

Purchased Equipment Year 4 (Purchase, Tax, Delivery)

Dep. Method	wc	Investment Year	0
Dep. Period	15.0	Lifetime	15
Salvage Value		TOTAL	$0

ANNUAL OPERATING COSTS - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration 09/26/2006 Op-Alt1-pg1

Annual Operating Costs	$ Amount

Direct Materials (Purchase, Delivery, Storage)

Escalation Rate	0.0%	Start Year	1
		End Year	15

Prefilters	$670,000
Replacement Filters	$665,000
TOTAL	$1,335,000

Utilities

Escalation Rate	15.0%	Start Year	1
		End Year	15

Fuel Costs ($1.34/gal)	$4,847,000
Potable Water ($0.50/gal)	$11,152,000
TOTAL	$15,999,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate	6.0%	Start Year	1
		End Year	15

Operating & Supervision (Base+ultrafiltration)	$43,998,000
Maintenance (base+ultrafiltration)	$2,993,000
TOTAL	$46,991,000

Waste Management (Labor, Materials)

Escalation Rate	5.0%	Start Year	1
		End Year	15

Greywater Hauling / Treatment / Disposal ($0.75 / gal)	$7,535,000
TOTAL	$7,535,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate	0.0%	Start Year	1
		End Year	15

Permitting (Item 13)	$0
Training	$0
Monitoring/Inspections/Audits (Item 1)	$0
Testing/Sampling Waste Streams (Items 7&8)	$0
Generator Fees/Taxes	
TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate	0.0%	Start Year	1
		End Year	15

Labeling	
Manifesting	
Recordkeeping	
Reporting	
TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate	0.0%	Start Year	1
		End Year	15

QA/QC	
Product Rejects (1 in 1000)	$2,012
Product Returns (1 in 1000)	$2,012
TOTAL	$4,024

Revenues - Product

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

Revenues - By-product

Escalation Rate	0.0%	Start Year	1
		End Year	15

Marketable By-products	
Marketable Pollution Permits	
TOTAL	$0

Insurance

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

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Future Liability

Escalation Rate	0.0%	Start Year	1
		End Year	15

Fines/Penalties	
Legal Costs	
Personal Injury	
Property/Natural Resource Damage	
Remediation	
TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

	$0
	$0
TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

Other

Escalation Rate	0.0%	Start Year	1
		End Year	15

TOTAL	$0

ANNUAL OPERATING COSTS - Alternative Scenario 2

Alternative Scenario 2: Using VCD 09/26/2006 Op-Alt2-pg1

Direct Materials (Purchase, Delivery, Storage)

Annual Operating Costs	$ Amount
Escalation Rate 0.0% Start Year	1
End Year	15
Prefilters	$670,000
Replacement Filters	$0
TOTAL	$670,000

Utilities

Annual Operating Costs	$ Amount
Escalation Rate 15.0% Start Year	1
End Year	15
Fuel Costs ($1.34/gal)	$4,847,000
Potable Water ($0.50/gal)	$11,152,000
TOTAL	$15,999,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate 4.0% Start Year	1
End Year	15
Operating & Supervision (Base+VCD)	$43,998,000
Maintenance (Base+VCD)	$3,824,000
TOTAL	$47,822,000

Waste Management (Labor, Materials)

Escalation Rate 5.0% Start Year	1
End Year	15
Greywater Hauling / Treatment / Disposal ($0.75 / gal)	$7,535,000
TOTAL	$7,535,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate 0.0% Start Year	1
End Year	15
Permitting	
Training	
Monitoring/Inspections	
Testing	
Generator Fees/Taxes	
TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate 0.0% Start Year	1
End Year	15
Labeling	
Manifesting	
Recordkeeping	
Reporting	
TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate 0.0% Start Year	1
End Year	15
QA/QC	
Product Rejects (1 in 1000)	$2,012
Product Returns (1 in 1000)	$2,012
TOTAL	$4,024

Revenues - Product

Escalation Rate 0.0% Start Year	1
End Year	15
Change in Product Throughput	
Change in Market Share	
TOTAL	$0

Revenues - By-product

Escalation Rate 0.0% Start Year	1
End Year	15
Marketable By-products	
Marketable Pollution Permits	
TOTAL	$0

Insurance

Escalation Rate 0.0% Start Year	1
End Year	15
Workers' Health Insurance	
Workers' Compensation	
Pollution Liability Insurance	
TOTAL	$0

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Future Liability

Escalation Rate 0.0% Start Year	1
End Year	15
Fines/Penalties	
Legal Costs	
Personal Injury	
Property/Natural Resource Damage	
Remediation	
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
TOTAL	$0

ANNUAL OPERATING COSTS - Base Scenario

Base Scenario: Disposal of Greywater by Backhauling 09/26/2005 Op-Base-pg1

Direct Materials (Purchase, Delivery, Storage)

Annual Operating Costs	$ Amount
Escalation Rate 0.0% Start Year	1
End Year	15
Raw Materials: HCl (M&E Item)	
Solvents	
Catalysts	
Other (Deionized Water)	
TOTAL	$0

Utilities

Annual Operating Costs	$ Amount
Escalation Rate 15.0% Start Year	1
End Year	15
Fuel ($1.34/gal)	$4,254,000
Potable Water ($0.50/gal)	$25,118,000
TOTAL	$29,372,000

Direct Labor (Wage/Salary, Benefits)

Escalation Rate 4.0% Start Year	1
End Year	15
Operating & Supervision	$42,533,000
Maintenance	$1,330,000
Other: HW Drums (M&E Item)	
TOTAL	$43,863,000

Waste Management (Labor, Materials)

Escalation Rate 5.0% Start Year	1
End Year	15
Greywater Hauling / Treatment / Disposal	$37,677,000
TOTAL	$37,677,000

Regulatory Compliance (Labor, Materials) #1

Escalation Rate 0.0% Start Year	1
End Year	15
Permitting (Item 13)	
Training/Instructing (Items 3&4)	
Monitoring/Inspections/Audits (Item 1)	
Testing/Sampling Waste Streams (Items 7&8)	
Generator Fees/Taxes	
TOTAL	$0

Regulatory Compliance (Labor, Materials) #2

Escalation Rate 0.0% Start Year	1
End Year	15
Labeling	
Manifesting	
Recordkeeping: MSDS/Emer Resp Plan Maint (Item 2)	
Reporting (Item 6)	
Other: HW Mgmt/P2 Plan Maint (Item 5)	
TOTAL	$0

Product Quality (Labor, Materials)

Escalation Rate 0.0% Start Year	1
End Year	15
QA/QC	
Product Rejects	
Product Returns	
TOTAL	$0

Revenues - Product

Escalation Rate 0.0% Start Year	1
End Year	15
Change in Product Throughput	
Change in Market Share	
TOTAL	$0

Revenues - By-product

Escalation Rate 0.0% Start Year	1
End Year	15
Marketable By-products	
Marketable Pollution Permits	
TOTAL	$0

Insurance

Escalation Rate 0.0% Start Year	1
End Year	15
Workers' Health Insurance	
Workers' Compensation	
Pollution Liability Insurance	
TOTAL	$0

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Future Liability

Escalation Rate 0.0% Start Year	1
End Year	15
Fines/Penalties	
Legal Costs	
Personal Injury	
Property/Natural Resource Damage	
Remediation	
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
Medical Exams - Medical Labor (Item 10)	
Medical Exams - Lost Labor (Item 11)	
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
TOTAL	$0

Other

Escalation Rate 0.0% Start Year	1
End Year	15
TOTAL	$0

SCENARIO SUMMARY - Alternative Scenario 1

Alternative Scenario 1: Using Ultrafiltration 09/26/2005 Summ-Alt1-pg1

INITIAL INVESTMENT COSTS	Cost	Salvage Value	Inv. Year	Lifetime	Depreciation Period	Depreciation Method
Purchased Equipment (Purchase, Tax, Delivery)	$2,219,904	$19,270	0	15	15	SL
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	350,000	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	100,000	0	0	15	15	WC
Permitting	50,000	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	6,478,416	0	0	15	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Deliver	3,808,512	33,060	1	15	15	SL
Purchased Equipment Year 2 (Purchase, Tax, Deliver	3,808,512	33,060	2	15	15	SL
Purchased Equipment Year 3 (Purchase, Tax, Deliver	3,808,512	33,060	3	15	15	SL
Purchased Equipment Year 4 (Purchase, Tax, Deliver	3,808,512	33,060	4	15	15	SL

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$1,335,000	1	15	0.0%
Utilities	15,999,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	46,991,000	1	15	6.0%
Waste Management (Labor, Materials)	7,535,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	4,024	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

SCENARIO SUMMARY - Alternative Scenario 2

Alternative Scenario 2: Using VCD 09/26/2005 Summ-Alt2-pg1

INITIAL INVESTMENT COSTS	Cost	Salvage Value	Inv. Year	Lifetime	Depreciation Period	Depreciation Method
Purchased Equipment (Purchase, Tax, Delivery)	$2,260,371	$19,270	0	15	15	SL
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	350,000	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	100,000	0	0	15	15	WC
Permitting	50,000	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	6,588,309	0	0	4	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Delivei	3,877,938	33,060	1	15	15	SL
Purchased Equipment Year 2 (Purchase, Tax, Delivei	3,877,938	33,060	2	15	15	SL
Purchased Equipment Year 3 (Purchase, Tax, Delivei	3,877,938	33,060	3	15	15	SL
Purchased Equipment Year 4 (Purchase, Tax, Delivei	3,877,938	33,060	4	15	15	SL

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$670,000	1	15	0.0%
Utilities	15,999,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	47,822,000	1	15	4.0%
Waste Management (Labor, Materials)	7,535,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	4,024	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

SCENARIO SUMMARY - Base Scenario

Base Scenario: Disposal of Greywater by Backhaulin	09/26/2005					Summ-Base-pg1
		Salvage			Depreciation	
INITIAL INVESTMENT COSTS	Cost	Value	Inv. Year	Lifetime	Period	Method
Purchased Equipment (Purchase, Tax, Delivery)	$0	$0	0	15	15	WC
Utility Connections/Systems	0	0	0	15	15	WC
Planning/Engineering (Labor, Materials)	0	0	0	15	15	WC
Site Preparation (Labor, Materials)	0	0	0	15	15	WC
Construction/Installation (Labor, Materials)	0	0	0	15	15	WC
Start-up/Training (Labor, Materials)	0	0	0	15	15	WC
Permitting	0	0	0	15	15	WC
Buildings & Land	0	0	0	15	15	WC
Working Capital	0	0	0	15	15	WC
Contingency	0	0	0	15	15	WC
Purchased Equipment Year 1 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 2 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 3 (Purchase, Tax, Deliver	0	0	0	15	15	WC
Purchased Equipment Year 4 (Purchase, Tax, Deliver	0	0	0	15	15	WC

ANNUAL OPERATING COSTS	Cost	Start Year	End Year	Escalation
Direct Materials (Purchase, Delivery, Storage)	$0	1	15	0.0%
Utilities	29,372,000	1	15	15.0%
Direct Labor (Wage/Salary, Benefits)	43,863,000	1	15	4.0%
Waste Management (Labor, Materials)	37,677,000	1	15	5.0%
Regulatory Compliance (Labor, Materials) #1	0	1	15	0.0%
Regulatory Compliance (Labor, Materials) #2	0	1	15	0.0%
Product Quality (Labor, Materials)	0	1	15	0.0%
Revenues - Product	0	1	15	0.0%
Revenues - By-product	0	1	15	0.0%
Insurance	0	1	15	0.0%
Future Liability	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%
Other	0	1	15	0.0%

GLOBAL PARAMETERS		SCENARIO PARAMETERS	
Project Title: Greywater Recycling			
Inflation Rate	0.0%	Default Investment Year	0
Discount Rate	3.5%	Default Lifetime	15
Aggregate Income Tax Rate	0.0%	Default Start Year	1
Default Depreciation Method	sl	Default End Year	15
Default Depreciation Period	15		

INCREMENTAL PROFITABILITY ANALYSIS

Analysis Name: Greywater Recycling 09/26/2005 Profit-pg1

P2/FINANCE calculates three indicators of profitability. (See on-line help for more detailed descriptions.)

Net Present Value (NPV), the most reliable indicator, is the value in today's dollars of the discounted future savings of a project. A positive NPV indicates a profitable project. When considering multiple projects, the most profitable project has the highest NPV.

Internal Rate of Return (IRR) is the Discount Rate for which the NPV of a project would equal zero. An IRR greater than the Discount Rate indicates a profitable project. When considering multiple projects, the most profitable project usually, but not always, has the highest IRR. IRR cannot be calculated for some projects with irregular cash flows.

Discounted Payback is the time period within which the discounted future savings of a project repay the Initial Investment Costs. A shorter payback period often, but not always, indicates a more profitable project because Discounted Payback does not account for cash flows that occur after the payback period. Discounted Payback cannot be calculated for some projects.

P2/FINANCE provides four time horizons for calculating Net Present Value and Internal Rate of Return. P2/FINANCE automatically calculates the profitability over 5, 10, and 15 years. You may choose an optional fourth time horizon between 1 and 15 years.

Optional Time Horizon 3

This analysis calculates the incremental profitability of each Alternative Scenario relative to the Base Scenario.
Base Scenario: Disposal of Greywater by Backhauling

Net Present Value ($)

Scenario	Name	Years 0-5	Years 0-10	Years 0-15	Years 0- 3
Alternative Scenario 1	Using Ultrafiltration	171,416,301	373,665,758	606,670,953	96,795,910
Alternative Scenario 2	Using VCD	182,472,240	414,027,359	691,087,168	100,992,400

Internal Rate of Return (%)

Scenario	Name	Years 0-5	Years 0-10	Years 0-15	Years 0- 3
Alternative Scenario 1	Using Ultrafiltration	416.9%	417.1%	417.1%	413.3%
Alternative Scenario 2	Using VCD	419.9%	420.1%	420.1%	416.1%

Discounted Payback (years)

Scenario	Name	Payback
Alternative Scenario 1	Using Ultrafiltration	0.26
Alternative Scenario 2	Using VCD	0.00

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The most obvious place to reduce cost in each of these systems is to minimize or reduce the use of prefilters because they are a capital expense, add complexity to the system, require daily maintenance, add a waste stream, and add a logistical tail. Unfortunately, both technologies that are feasible require prefiltration.

The only solutions that currently present themselves are the use of a small-diameter tubular filter with the appropriate amount of surface area or prefilters that can be cleaned and reused. Both of these options should be investigated in the future.

6.2 PERFORMANCE OBSERVATIONS

While the spiral-wound ultrafilter did not produce permeate that was low enough in BOD to meet the secondary treated water goal, the quality seemed good enough for washing and rinsing dishes. This is a matter that will be brought up to USACHPPM and discussed.

6.3 SCALE-UP

There are no scale-up issues associated with these technologies. On the contrary, these systems would benefit from miniaturization. The smaller, lighter, and more portable the device is, the more attractive it is to the Army.

6.4 OTHER SIGNIFICANT OBSERVATIONS

As discussed in Section 4.2, none of the technologies satisfied all the performance criteria. The Ovation Products VCD produced clean water that satisfied the secondary treated water quality standard but was too heavy and delicate for feasible fielding. Infinitex's Splitter XD ultrafilter is small, light, and rugged, but the BOD was too high in the permeate to satisfy the water quality standard. The Bristol International tubular ultrafilter permeate water quality was very poor and is not feasible for field use.

In light of this, there is hope for two of these products to be useful in the field. Ovation Products is currently developing a smaller, lighter, more rugged VCD system that could meet the Army's specifications. Meanwhile, working with USACHPPM could result in a new sink water standard that allows for less-than-potable water quality, thus allowing the use of spiral-wound ultrafiltration.

6.5 LESSONS LEARNED

The first lesson learned concerns prefiltration. The prefilter used for the Infinitex Splitter XD ultrafiltration system, which consisted of a large bag filter and a sump pump, was outperformed by a very simple set of two 30-micron cartridge filters and a submersible gear pump. The gear pump was able to deliver a high head pressure at a low flow, which was able to continue to force water through the cartridge filter as it became fouled. The bag filter was large, clumsy, and at times ineffective due to the horizontal orientation of the housing. This allowed much of the

water to skirt around the filters. The lesson learned is twofold: (a) bag filters should always be used in a vertical orientation, and (b) the proper pump can insure the effectiveness of cartridge filters.

6.6 END USER ISSUES

The primary stakeholder is the combat developer, the U.S. Army Combined Arms Support Command (CASCOM). This demonstration addressed their concerns for a low-powered, light, durable system that is easily operated by inexperienced soldiers performing kitchen police (KP) duties.

This demonstration did not address cold weather operation, a requirement for both this system and the system that it supports, the FSC. This requirement will be addressed when choosing between systems.

As with much Army field kitchen equipment, systems are designed so that most parts are field replaceable, and only a few maintenance actions require a depot. In the case of Infinitex's Splitter XD ultrafilter, the only moving part is the pump. All the other parts such as the ultrafilters, the hoses, the housings, and the fittings can be replaced in the field.

The Ovation Products VCD system is more complex and unique and would require many maintenance actions to be performed in a depot. The extent of time spent on maintenance and in a depot will have to be determined before the decision is made to procure the item.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

USACHPPM will be the contact point for regulatory compliance. They determine the regulations that are the basis for doctrinal documents such as TB-Med 530[9], FM-10-23[10]. By working with them to understand the mission, we can arrive at a new standard for recycled greywater for washing and rinsing cookware. In conjunction with this report and the hard data from the field, we will submit to USACHPPM data that shows, quantitatively, how dirty the ultrafiltration permeate is compared to slightly used sink water, and how long the recycled water can be used before bacteria counts increase.

7.0 REFERENCES

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APPENDIX A

POINTS OF CONTACT

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